DETERMINATION OF TEMPERATURE, WINDS AND PARTICULATE CONCENTRATIONS IN CONNECTION WITH OPEN FIELD BURNING

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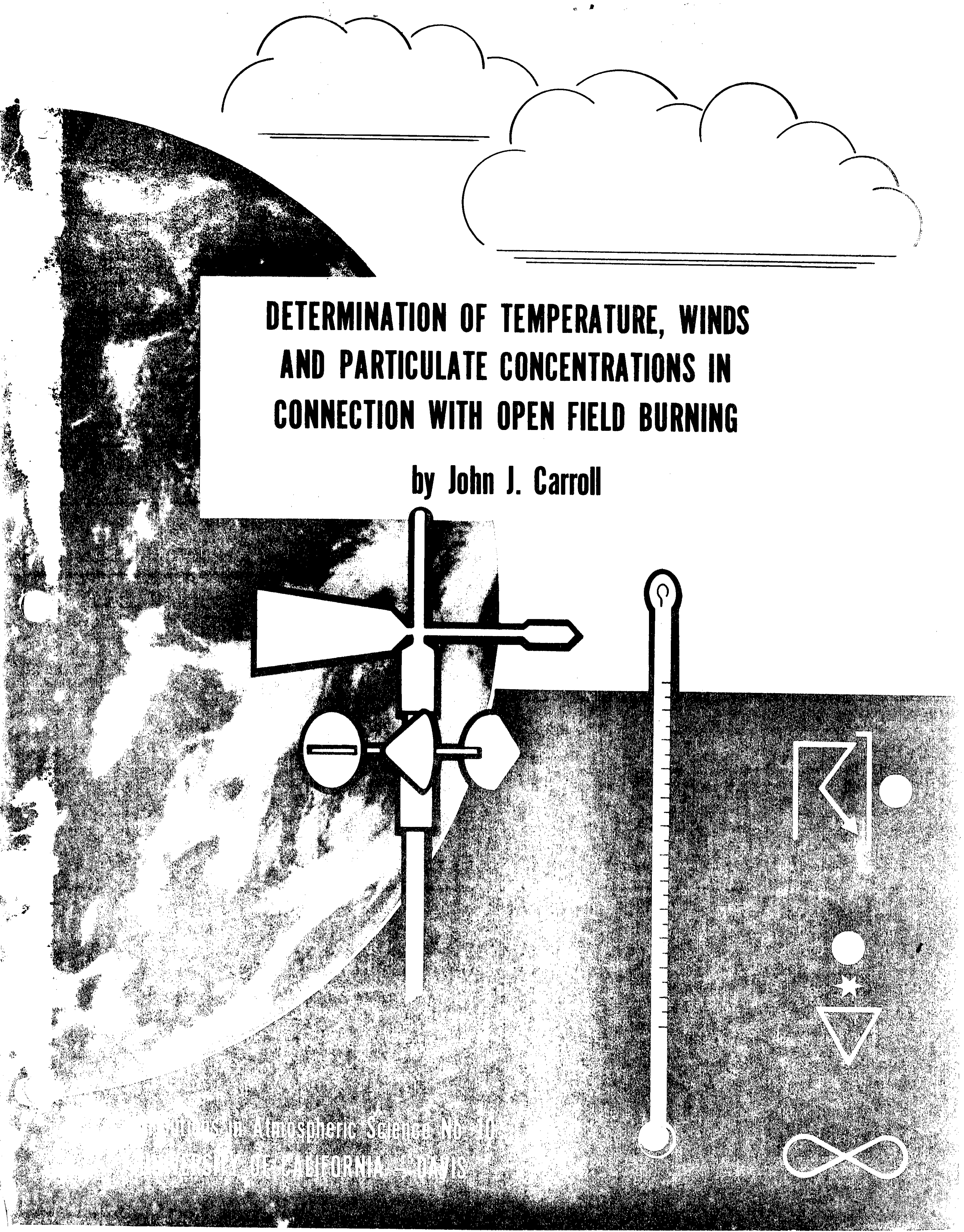

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Abstract

An investigation of plume rise and smoke characteristics from open field burning of agricultural residues is reported. The design and execution of a program for measurement of smoke from such fires using a light twin-engined aircraft is described as well as the data analysis techniques and procedures. Two appendices are included, one containing sample soundings of the vertical distribution of temperature, wind, absolute humidity, and particulate concentrations; and the other data on particulate concentrations and size distributions (for particles larger than 0.4 microns [μ] in diameter) for individual fire plumes. The results are summarized as a qualitative analysis of plume rise from various types of fires under various meteorological conditions and as quantitative averaged comparisons of particulate emissions and their physical characteristics with fire type.

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Summary and Conclusions:

The behavior of plumes from open field burning is somewhat different from the plume rise characteristics of elevated stacks. The major difference is that plume rise from an open field burn is very sensitive to both wind speed and to fire type (i.e. front, back or perimeter fire). As a result, the choice of the optimal fire strategy depends on whether total emissions are to be minimized or if ground level concentrations downwind of the source are to be minimized. The distinction between these two criteria is made in part because of the behavior of buoyant plumes from ground level sources and in part because of the differences in emissions from different fire types.

For a given fuel concentration, maximum plume rise is obtained with front fires in light winds. The reason for this is that in light winds, a well-defined vertical plume develops over a front or perimeter fire which is fairly efficient at deep vertical transport of the effluents. If an elevated stable layer is present, which is usually the case in the Central Valley on light wind days, effluents are injected into the lower part of the stable layer. They are then transported downwind as an elevated, thin layer of smoke with little or no downward diffusion. The same is true for backfires except that the plumes from backfires are significantly cooler and therefore are not as effective in penetrating the elevated stable layers.

With wind speeds increasing above about $2 m\text{-}sec^{-1}$, the near ground particulate concentrations downwind from a fire increase rapidly, especially for front fires. At the higher wind speeds, front fires are more complicated in their plume structure. This is because there are two sources associated with the one fire; the hot active flame front and the smoldering burned over area. The temporal and special separation of these areas increases both with wind speed and with size of the field burned. The wind also inhibits the development of a well defined vertical plume which decreases the efficiency of the vertical transport of fire emissions. In addition, the increased turbulence near the ground associated with increased wind speed results in considerable fumigation of the smoke plume downwind from the fire. This will occur for both front and backfires but since front fires have significantly higher emissions, primarily from the less buoyant smoldering areas, the ground level concentrations downwind of front fires will be proportionally higher than for backfires.

The concentration of smoke in front fire plumes is about 7.3 times greater (by mass) than that in backfire plumes. This difference is due to two factors. The first is that backfires burn 3 to 5 times more slowly than front fires and therefore the fuel consumption per unit time is proportionally less. The second factor is that backfires accomplish more complete combustion of the fuel so that particulate emissions from backfires are nearly 50% less (by mass) per unit of fuel burned. Therefore, backfiring reduces both total emissions of particulate and concentrations. However, in light winds with an elevated stable layer, front fires - while having higher total emissions - will tend to inject these emissions aloft, so that ground level concentrations will be low for either type of fire under light wind conditions.

A series of tests have been made with a third type of fire by Miller's group, with only one of these being monitored by the aircraft system. The aircraft results have not been included explicitly in this report, due to lack of statistical significance. This fire technique is being called into-the-wind-stripfiring, in which the field is ignited in lines oriented parallel to the wind direction starting from the downwind end of the field. Preliminary evaluation of these fires indicate that their plume rise characteristics appear to be comparable to front fires, whereas the emission characteristics are between front and backfire emissions.

Stacked fuel and pile fires tend to be the dirtiest because the smoldering stage dominates the combustion process once the surface fuel has been consumed. This is apparently due to oxygen depletion within the stack, preventing significant oxidation.

Implicit in the choice of the optimum burn strategy is the relative costs associated with fire type. A cost analysis by Miller's group, indicates that front firing costs \$0.12 to \$0.19 per acre, stripfiring \$0.25 per acre, and backfiring about \$0.65 per acre. These figures are of course approximate, but serve as a useful basis for comparisons with non-combustive disposal. Costs of soil incorporation in fields which are not double cropped can be compared using a study by Kepner and Burkhardt (1972) for rice straw which showed that under optimum field conditions (dry fields) incorporation would cost as little as \$2.00 to \$3.00 per acre. Costs for residue utilization are considerably higher in that baling and roadsiding of rice straw alone would cost between \$21.00 and \$28.00 per acre (Dobie, et al. 1973). Since both incorporation and baling require additional mechanized treatments, the current fuel shortages will probably preclude serious consideration of these alternatives regardless of these 1971 cost per acre figures.

Quantitative data on the concentration of particles larger than 0.4μ diameter indicate that the number of particles per unit volume of air in the plume is 5.5 times higher for front fires than for backfires and about 10 times higher for pile fires. The increased emission from the pile and front fires appears to originate primarily from the smoldering effects typical of these fires. For the four cases in which the smoldering plume and active fire plume from the same fire could be monitored separately by the aircraft, smoldering concentration (by number) was 4.4 times that of the active plume. The number-size distribution is also different with nearly 99% of the active particles being less than 1.3μ versus only 85% of the smoldering particles being less than that size.

Another result relevant to this discussion is the apparent morphology of the smoke particles. The vast majority of particles greater than 1.3μ in diameter appear to be crystalline or solids which are presumed to be silica, soil minerals and ash. However, 50% to 70% of the particles between 0.7 and 1.3μ and 92% to 98% of the particles between 0.4 and 0.7μ appear to be liquids. Ground level measurements show similar results plus the fact that most of this material is chloroform soluble. Furthermore, smoldering emissions are predominantly of this type. The data developed here and from other laboratory and field studies supports the hypothesis that most of the smoke particles less than 1.3μ in diameter are recondensed hydrocarbons distilled from the fuel or the product of only partly oxidized fuel. The chemistry of these liquid particles is not known to any significant degree, but probably includes olefins, aldehydes, keytones and other large molecule groups. The data on aged plumes indicates a size shift to smaller sizes among the liquids, suggesting a slow reevaporation with time.

Since the chemistry of these liquids is not known, it is difficult to assess any special hazard associated with them or their potential for reacting to form hazardous secondary pollutants. The evidence at hand suggests that these particles probably can have deleterious effects on human receptors, since the large number of particles in the submicron range mean a high potential for lung accumulation of these particles, and since most of them appear to be "tarry" hydrocarbons. Since smoldering is apparently the major source of increased emissions from non-backfires and since most of the smolder emissions appear to be these liquids, significant reduction of these emissions can be accomplished by the exclusive use of backfiring. While backfiring is three times as expensive as front firing, it is still at least 4 to 6 times cheaper than the least expensive noncombustive disposal technique.

Recommendations:

On the basis of information developed by this project, the collateral work by Miller, et al, and that of others reported in the literature, the following recommendations are made.

1. Backfiring should be strongly encouraged.
2. Under very light wind conditions, a number of front or small peripheral fires may be permitted without seriously degrading the ground level air quality. However, the acreage burned in any one area should be limited to avoid an excessive "overcast" of smoke.
3. Burning with strong ground level winds (>>2 m sec^{-1}) will result in high ground level smoke concentrations because of strong fumigation effects. These would be worst for front fires, less for strip fires and least for backfires.
4. If front fires are to be used, efforts to minimize the separation of the smoldering zone from the active zone should be made. The smaller this separation, the higher the percentage of smoldering emissions that will enter the flame zone. This should allow more complete oxidation of these emissions and therefore fewer particulates should be emitted. This can be attained by limiting the downwind dimension of a front fired field.
5. Further investigation of the nature and chemical composition of the liquid emissions which account for the vast majority of the submicron smoke particles should be pursued. The practical objectives of such a study would be to access their inherent toxicity, their potential for participation in photochemical smog reactions and possible suppression techniques.

Introduction:

The open field burning of agricultural residues is presently a widely used technique for field sanitation as well as waste disposal. Until less harmful means of pest control are available and until other economically viable techniques for residue utilization or disposal are developed, agricultural burning is likely to continue. With the prospect of continued burning, the goal of air pollution control agencies is to minimize the degradation of air quality caused by this source.

The characteristic emissions from combustion of agricultural residues is well documented for laboratory situations (e.g. Boubel et al, 1969; Darly et al, 1966) and fairly well documented for field situations (e.g. Meland and Boubel, 1966). For grass type fuels, burned in a laboratory situation, typical emissions in units of pounds per ton of fuel burned are: particulate (15), CO_2 (2000), CO (100) carbon (9), and unburned hydrocarbons (i.e., olefins, acetalene, ethylene, etc. 10). Since combustion temperatures are normally less than 1000°C, NO_x production is quite small. Therefore, the effluents from open field burning by themselves are not expected to be photochemically very active.

The most obvious effects of burning on local air quality are visibility reduction and odors. However, the emissions of large numbers of particulates of which many are "tarry" hydrocarbons suggests a serious potential for lung irritation in the receptor.

Efforts to minimize ground level concentrations have centered on the restriction of the amount of fuel burned in a given area in accordance with forecast meteorological conditions. These are primarily the vertical dispersion potential and horizontal transport expected (e.g. Thuillier and Sandberg, 1971; Duckworth, 1965).

An additional means of reducing downwind concentrations is the reduction of particulate and hydrocarbon emissions at the source by improved combustion efficiency. This report is primarily concerned with the evaluation of the effectiveness of various field practices (i.e., front firing, backfiring and fuel stacking) on particulate emissions. Meteorological data are also presented and may be used to verify burn condition forecasts for selected days during the 1971-73 burning seasons. Also included in the overall effort was a photographic and visual study of plume rise and behavior as a function of local wind and temperature structure and firetype. Finally, in addition to the total particulate concentrations, the size distributions of the particulates as a function of the same variables was sought.

Experimental design:

The successful attainment of the goals outlined above required measurements both at ground level and in the air above and around a fire. The latter measurements are best obtained from a mobile platform such as an instrumented light aircraft. With this mobility, measurement of atmospheric thermal structure in both horizontal and vertical domains is easily obtained as well as the three dimensional distribution of particulate concentrations, water vapor and any other variable of interest. This mobility also allows repeated plume penetrations at any desired altitude or distance downwind of the source. This repeat capability makes it possible to sample the plume throughout the duration of a burn, thereby permitting measurement of the average emissions from the fire as a whole. This document reports on the aircraft observation phase of this program.

The ground level measurements were conducted under a separate project under the direction of G. E. Miller and J. R. Goss (1973). The two projects were coordinated so that relevant ground level data would be available for the aircraft sampled fires. The detailed description of the ground level study is reported separately.

A major effort in this study was the development of an aircraft instrumentation system which would consistantly deliver accurate data with minimum sensitivity to operator fallibility. The configuration of the system evolved during the early course of the project, achieving final configuration in October, 1972. The major difficulty encountered during the first stages of this project was the determination of the net contribution of a fire to the total plume smoke concentrations. With a nonzero background particulate concentration, accurate knowledge of the background concentrations, plume residence time of the aircraft and total sampling time are required to permit evaluation of the net plume concentrations attributable to the fire and to evaluate the net particle size distribution.

Pursuant to these objectives, several major acquisitions were made. The first of these was the purchase of a Climet 250 Portable Particle Counter ($1800; purchased with Contract Funds). The second was a 500 watt 24 V DC to 110 V AC high quality inverter ($700; no cost to Contract) and the third was a six channel compact, oscillographic recorder ($4000; no cost to project). The graphic recorder was the main data recording system.

For the operations related to this project the following instruments are continuously monitored: one low and one high sensitivity, fast response thermometer (spacial resolution at 100 mph = 14 ft.), a Lyman - α hygrometer, altimeter and the particle counter. The sixth channel could be used for air speed, RMS velocity fluctuations or total oxidents if the application required. A block diagram of the instrumentation is provided in Figure 1.

The Climet 250 is a totalizing counter for particles having equivalent optical diameters > 0.4μ. This was first available for operational use in late spring, 1972. In June and July several burns were monitored using the Climet 250 to measure particulate levels. While the data obtained was extremely useful, the totalizing mode of operation and its concomitant finite sampling period (36 or 360 seconds in automatic modes) gives very little spacial resolution (i.e., 1 to 10 mi at 100 mph). Furthermore, the instantaneous particle loading would be the best indicator of plume size. Therefore the counter pulses were fed to an external integrating circuit designed to give an analogue voltage proportional to the rate at which the counter is detecting particles. Thus, continuous data on the instanteous particulate concentrations were graphically recorded with the total, averaged levels summarized on the counter's digital display.

The particle collection system is an integrated unit with a single Start/Stop control which activates a) the particle counter (Manual mode), b) a digital, crystal controlled elapsed time counter, and c) a high capacity vacuum pump which draws the sample through a type H.A. Millipore filter (0.45μ mean pore size) at 0.75 CFM. With this system the operator can initiate a sample with all samplers being activated simultaneously and a precise record (0.1 sec resolution) of the duration of the sample automatically available. A vocal cassette tape recorder is used to record the flight log as well as the summary counts from the particle counter, the elapsed time, etc. The particulate samples for the two systems are drawn through separate tygon tubing from each of two orifaces which are designed to provide isokinetic samples at 100 mph air speed.

The operational procedure for the flights are as follows. After a preflight check of the instrumentation and take off, a preliminary sounding was made enroute to the test site to locate significant inversions, if any, below

4000'MSL. At the site a descending sounding was performed which included continuous collection of particulates for microscopic analysis of size distribution. At the end of the sounding, the filter was changed in preparation for plume penetrations and the ground crew signaled to begin the burn. After a well established plume developed; a series of plume penetrations were performed with all sensors operational and the syncronous particulate sampling system activated shortly before penetration and terminated upon exiting the plume. Depending on the type, size and behavior of the fire and its plume, several sets of penetrations may have been performed with the filter being changed between sets of passes. If ambient conditions appeared to be changing significantly during the plume passes, a second sounding would be performed at the end of the set(s) of passes.

In addition to the aircraft measured variables, double theodolite pilot balloon observations were made during the 1971 and the summer 1972 field observations. The inclusion of these measurements of the vertical profile of the horizontal wind was intended as a means of specifying plume rise dependence on wind profiles. These observations were discontinued when it was found that the wind measured 6 ft. above ground appears to be sufficient to define plume behavior.

Finally, since for the same atmospheric conditions, particulate emissions from a given fire will depend on fuel moisture content, fuel concentration, rate of fuel consumption, flame temperature, etc., these data are required to normalize the observed net fire particulate emissions. These data plus ground level wind speed are also of major importance to the ground level project and were provided to us, when available, by Miller's group.

The typical size of the experimental fires studied in this project is generally smaller than the typical size of operational fires. The plots burned for monitoring purposes ranged from about 0.5 to 5 acres. There were several reasons for limiting this size. First, by burning only parts of a given field at a time, several techniques can be tested within the same field so that the relative effects of each technique can be evaluated with reasonable assurance that the fuel state, field conditions, etc., are comparable among burns. Secondly, plume turbulence would be expected to be larger with larger front or perimeter fires thereby seriously increasing the hazard to aircraft operations. Finally, larger space scales also imply larger time scales for a burn. The time required for sampling both from the ground and the air is amply available for the plot size used. In addition, quantitative evaluation of the relative effects of burning techniques is more significant if a set of fires can be monitored within a short enough period that the ambient wind and stability conditions and the fuel state - primarily its moisture content - are nearly constant. Therefore, with the smaller areas burned the quantitative data on particulate concentrations and plume temperatures are probably under estimates of what would be expected for large permimeter or front fires. The data for backfires is probably independent of the size of the plot burned.

Data analysis:

A. Ambient Conditions:

The aircraft soundings of temperature, specific humidity and particulate concentrations were plotted in a standard format and are presented in Appendix A. When available, the double theodolite measured wind profiles are also included. The data was measured at various times in an irregularly spaced sample of 11 burn days between August 1971 and April 1973. Prior to June 1972, vertical distributions of particulate concentrations were not available. The soundings for June and July 1972 were obtained using the 36 second sampling mode of the particle counter and therefore represents an average through a volume 1 mile long and 55 m (180') deep at the normal airspeeds and climb rates of the aircraft. All soundings later than August 1972 contain detailed distributions obtained from the continuous output, "instantaneous" concentration circuit described in the previous section. The geographic location of all soundings is within the area defined by Davis, Sacramento metropolitan airport, Marysville, and Knights Landing.

B. Particulates:

The totalized Climet 250 data was the primary source of information on the number density of particles larger than 0.4 microns in diameter. The size distribution within this population was determined by manual microscopic analysis of the millipore filters. A secondary source of information on the total number density was afforded by the microscopic analysis. Cross comparisons between the Climet output and manual counting for two special calibration samples indicated the two independent estimates were within 5% of each other.

The microscopic analysis was performed using a Zeiss Ultraphot II microscope equipped with Nomarski differential interference contrast condenser, objectives, etc. Since the Nomarski DIC technique requires transmitted light, the samples to be analyzed were mounted immersed in an immersion oil which has the same index of refraction as the filter material, thereby rendering the optical background a uniform field. Any material within the field of view which has an index of refraction different from the filter - oil combination will produce identifiable interference phenomena. This is true for both liquid and solid particles. The specific advantages of the Nomarski DIC technique are very high magnifications with high resolving power and little to no shape or size distortion. This technique is also especially suited for distinguishing spherical from angular particles. The magnifications used in this study ranged up to 680x with a capability of resolving particles $\gtrsim$ 0.4μ in diameter. Therefore, both the Climet data and the manual counting data have the same size threshold.

The size distribution data reported here were determined by manual analysis of about 0.005% of the total filter area using a calibrated gradicule in the occular to determine the size of particles viewed. Differentiation between amorphous and angular particles was made when possible. Tests of the filter collection characteristics showed that over 95% of the active collection area, the total loading per unit area and the size distribution within any area is invariant. The significance of the reported statistics is insured since the number of particles counted must exceed a minimum of 300 per sample independent of how much of the filter must be viewed to attain this count. Finally the confidence in the data so analyzed is enhanced by the availability of the independent Climet data. The size distribution is expressed as the percent of particles that are within a size range.

A variety of automated and semi-automated particle counting - sizing techniques were explored in an effort to eliminate the slow, tedious task of manually counting the particles. These included analysis of high contrast photo-micrographs (taken through the Ultraphot) both manually and using an image analyzing computer. Direct vidicon imaging of dark field Microscopy into an image analyzer was also tried. The manual photoanalysis showed no real advantage over direct microscopic, manual analysis. The automatic techniques were unsuccessful because of insufficient contrast differences between particles and background coupled with serious size distortions in the contrast enhanced images.

The use of the type HA filter (esters of cellulose) also lends itself to analysis of species using the UCD-ARB aerosol analysis system developed at the Crocker Nuclear Laboratory. Sample results of one such analysis is shown in Table 1. However, the low concentrations and short penetration times inherent in the aircraft data result in relatively light loading of the filters. Therefore, our samples are too sparse for meaningful activation-species analysis.

C. Net fire contributions:

Essentially two classes of particulate data were measured, background data and plume penetration data. Each class in turn consists of two types of information: the total concentration by number (> 0.4μ diameter) and the relative size distribution (> 0.4μ diameter). Since a penetration pass would collect particles even with no fire present, attainment of the project objectives required that the net contribution and size distribution due to the fire itself be determined.

The net concentration was determined by analysis of the recorded instantaneous particulate concentrations. From these the background concentrations at the time and altitude of a pass as well as the total concentrations within the plume are determined. By subtracting the time weighted background from the plume totals, the net fire contribution to the total concentration is determined. Averaging over all passes gives the average fire input of particulates.

Determination of the net fire size distribution is more difficult and also somewhat suspect in certain cases. From the background size distribution obtained from the sounding filter; from the mean background concentrations at pass times and elevations; and from the total exposure time of the filter, the number of particles in each size range attributable to the background is determined. The size distribution on the penetration filters is measured

Figure 1 Block diagram of aircraft Instrumentation.

TABLE 1

Results of activation analysis of particulates sampled in active Plume on 7/31/72

elements detected	amounts [$\mu gm/m^3$]	confidence units [$\mu gm/m^3$]
Silicon	4.7	± 1.6
Calcium	4.4	± 1.1
Potassium	1.1	± 0.5

undetected elements	detection threshold $\mu gm/m^3$
Sodium	13.8
Magnesium	6.90
Aluminum	2.76
Phosphorous	1.38
Sulfur	0.69
Chlorine	0.69
Iron Region	0.41
rare earths	1.66
intermediate and heavy metals	0.55 - 1.10

directly. Then substracting the particles attributable to the background from the pass totals in each size range, the net fire distribution is found.

Two major difficulties are inherent in this technique. The first is the assumption that the size distribution in the background particulate populations remains constant from the time of their sampling through the time of the plume penetrations. During periods of rapidly changing background concentrations this assumption appears to be invalid and the net fire size distribution is probably in error. The second difficulty manifests itself when the net fire concentration is a small fraction of the total plume load, i.e. a clean fire in a dirty atmosphere. Under such conditions, small percentual counting errors or small shifts in the background size distribution will dominate the net distribution. For example, suppose the net concentration from a backfire is 0.8×10^7 particles/m^3 in a background of 2.4×10^7. The total plume concentration would therefore be 3.2×10^7 #/m^3. A 10% error in any one size range for the total plume represents a 30% error in net particles for that size range.

Estimates of the gravimetric concentrations can be made from the number concentrations and size distribution data. The key to this transformation is a reasonable estimate of particle density. Laboratory data on combustion of this type as well as ground level measurements from this program, indicate that a large number of particulates are cloroform soluble hydrocarbons, presumably the recondensed distillate from unburned fuel. As such, they should appear spherical to amorphous in shape. Soil and mineral particles on the other hand should appear angular or crystalline in shape. Reasonable estimates of specific gravities would therefore be 0.8 for the amorphous particles and 2.5 for the angular particles. Given these assumptions and a size distribution for both the angular and the amorphous particles the total mass concentration and mass size distribution can be calculated.

The background, penetration and net particulate data for each trial are presented in Appendix B. Also presented is the available data on burn conditions, ambient wind, type of fire, et al. The net fire data is only included for those cases for which reasonable significance can be attached to the results.

Results:

A. Ambient Conditions

The most obvious feature in the sounding data is the frequency of samples in which significant daytime isothermal or inversion layers occur at altitudes less than 455 m (1500 ft) - especially during the summer and early fall. Most of these stable layers are also apparent in the moisture profiles which show decreases in absolute humidity above these layers confirming expectations that subsidence is the cause of their formation.

The presence of these layers is also indicated in most of the particulate profiles in that a local maximum in the particulate concentration often occurs at the base of these layers and in general the particulate concentrations decrease rapidly above them.

The average concentrations of particulate ($> 0.4\ \mu$ in diameter) for all 25 soundings taken on these days is 6.6×10^7 particles m^{-3}. The range for the sample is between 0.18×10^7 to 28×10^7 particles m^{-3}, with a standard deviation of 8.5. Extremely large and rapid changes of ambient particulate not associated with an identifiable fire plume were observed on the afternoons of March 27 and March 29, 1973. On both occasions ambient levels were about 5×10^6 part. m^{-3} at about 2 PM and increased to about 240×10^6 part. m^{-3} in the course of about an hour. This increase appeared to be the result of the transport of well diffused smoke from fires 30 to 50 miles away.

The particulate sounding data are included in this report primarily to provide heretofore nonexistent data on the particulate concentrations and their vertical distribution over rural areas of the lower Sacramento Valley.

B. Plume Rise

As expected, two factors were found to have a large effect on the behavior of buoyant plumes from ground level sources. These are the presence of an elevated stable layer and the speed of the wind near the ground. In the limit, the maximum rise of the effluents is to the lowest significant stable layer.

The predominant effect of wind, especially at ground level, is to reduce the efficiency of buoyant accelerations in terms of total plume rise. With very light winds ($\leq$ 1 m sec^{-1}) and with fires in areas larger than about one acre, a well defined nearly vertical columnar plume usually develops. In the absence of any significant stable layers, these plumes diffuse radially as they rise eventually resulting in a very diffuse, elevated cloud transported downwind by the mean flow. With an elevated stable layer present - which is more commonly the case in the Central Valley - the effluent spreads horizontally at the base of or within the lowest part of the stable layer in a form similar to that shown in Figure 2. Since the effluent is then embedded in a layer with a large static stability, vertical eddy diffusion is strongly suppressed and the effluent is transported downwind as a thin layer, diffusing horizontally with almost no vertical diffusion.

At wind speeds greater than about 2 m sec^{-1}, two separate effects prevent the formation of a well defined vertical plume. The first effect is that each buoyant parcel is not emitted into the wake of the previous parcel as in the case of very light winds. Therefore, each emitted parcel must expend energy in generating its own path vertically through the ambient air. In addition the entrainment loss of buoyancy is higher in this case because such parcels are surrounded by ambient air rather than by the plume-air mixture as in the case of the vertical plume. The second effect of increasing wind speeds is an increase in mechanical turbulence in the wind field itself. This ambient turbulence further increases the entrainment rate, especially near the ground, further reducing parcel buoyancy. This combination of factors produces a plume which is more horizontal than vertical in orientation, even for large hot fires.

A schematic side view of the behavior of a front fire plume with moderate to high wind speeds is shown in Figure 3. A significant characteristic of front fires is also shown in the figure. This characteristic is that smoke from a front fire is generated from two distinct subsources. The first is the active flame front, and the second is the smoldering burned over area. The temporal and spacial separation of these two subsources increases with both the low level wind speed and the length of the burning field in the downwind direction. Visual evaluation of smoke density clearly indicates the particulate concentration is much less from the active fire areas than from the smoldering areas. Due to the pre-existing mechanical turbulence near the ground, fumigation of both plumes occurs with the result that ground level concentrations remain high at considerable distances downwind of the fires. Since the smoldering plume is far less buoyant than the active plume, fumigation of the former, dirtier plume is more pronounced.

The characteristics of backfire plumes are comparable to those of the active plumes from front fires but with no significant smoldering sources. Although fumigation of backfire plumes also increases with increasing wind speed, the relatively low source strength results in a minimal degradation of ground level air quality downwind of a backfire.

The apparent benefit of reduced ground level concentrations with backfiring must be evaluated against significant cost differentials implicit in front versus backfiring operations. Since backfires burn nearly three to five times longer than front fires for the same field conditions, labor costs per acre are proportionally higher unless the fires are left unattended. In addition, with increasing wind speeds, backfires do not burn consistently, often burning out locally or completely. This results in patchy burn coverage if relighting is not performed.

Based on these qualitative observations the following conclusions are reached regarding the operational practices for burning that will minimize the ground level particulate concentrations downwind of open field burns.

1. At wind speeds less than about 1 m sec^{-1} near the ground, typically sized perimeter and front fires will develop continuous vertical plumes which act as efficient natural chimneys carrying effluents to considerable heights. If an elevated (i.e. few hundred meters) stable layer is present, the effluent will be injected into and trapped within this layer. While such a fire will normally produce a fairly high concentration of effluent, the material will, under these ambient conditions, be confined aloft and transported downwind with almost no downward diffusion. While this elevated smoke layer would have considerable effects on local aesthetics and on local radiative transfer processes, exposure of ground level receptors to the effluents would be minimized. Under the same conditions backfires would not be quite as efficient since the available buoyancy in the plume from a backfire is less and therefore its probability of injecting most of the effluent into the stable layer is reduced.

2. At wind speeds greater than about 2 m sec^{-1} ground level effluent concentrations will be greatly reduced with backfiring but with considerable increases expected in operational costs.

C. Plume Temperatures

One of the most surprising results obtained from the penetration of fire plumes was the small magnitude of the temperature excess measured within the plume. For backfires the difference in temperature between the plume and its horizontal environment at an altitude of 30 to 100 meters above the fire, were 0.1°C or less. Front fire plumes were generally warmer having peak temperature excesses of 0.5 to 3.0°C. These plume temperature differences were often comparable to or less than the amplitude of the temperature fluctuations associated with normal thermal activity in the area. As a result only rarely could temperature data be used to identify plume penetrations in the records.

Since the source temperatures for the fire plumes was expected to be much higher than the naturally heated surfaces, the comparable plume temperatures at altitudes greater than 30 meters implies a very high net heat loss in the fire plumes during the first few 10's of meters rise. This loss can be attributable in part to radiative loss and in part to very rapid entrainment of ambient air within the fire zone itself. The radiative heat transfer is an important mechanism for continued combustion in that the radiated energy preheats unburned fuel, raising it toward its flash point. Some of this energy also is used to evaporate moisture from the fuel as well as contributing to the distillation of liquid hydrocarbons from the unburned fuel. In addition, the radiant energy is also absorbed by the soil and ash surrounding the fire zone, with the result that the heated area which defines the base of the fire plume is considerably larger than the flame zone so that the areally averaged source temperature for a plume is expected to be less than the flame temperature.

In addition to the radiative losses and their effects on source area size, considerable entrainment is expected immediately above the flame zone. The intense local buoyant accelerations driven by temperature excesses the order of 500°C in the flame zone will generate intense local vortex ring circulations, as illustrated in figure 4, which are very efficient at entraining ambient air. These eddies plus any turbulent eddies in the ambient wind field produce a rapid dilution of the plume immediately above the flame zone. Therefore, the vertical acceleration in the plume as a whole is only a small fraction of that which would be calculated from the flame temperatures themselves.

The reason for the strong dependence of the plume rise characteristics on ambient wind speeds discussed in the previous section can be further delineated from the aircraft temperature observations. The local vertical acceleration per unit mass due to buoyancy alone is given by:

$$\frac{\partial w}{\partial t} = - \bar{u} \frac{\partial w}{\partial x} - w \frac{\partial w}{\partial z} + \frac{\Delta T}{T} g + \nu \nabla^2 w \qquad (1)$$

where: w is the local vertical velocity

$\bar{u}$ is the mean horizontal wind speed

x is the coordinate parallel to the mean wind direction

z is the vertical coordinate

ΔT is the temperature difference between the parcel and its horizontal environment

T is temperature of the parcel

g is the local gravitational acceleration

and ν is the kinematic viscosity.

For the temperature excesses measured in the plumes the buoyant accelerations ($g\Delta T/T$) would range from 0.3×10^{-3} m sec^{-2} for $\Delta T \simeq 0.1°C$ to 0.01 m sec^{-2} for $\Delta T \simeq 3°C$. As mentioned above, a large percentage of the acceleration is manifested as secondary flows and is not wholly converted to a mean updraft velocity. Furthermore, buoyant acceleration is reduced by frictional dissipation which further reduces the magnitude of the mean updraft speed within the plane.

The role of the mean wind in altering plume behavior is implicitly contained in equation (1) and in the characteristics of the ring vortex structure sketched in figure 4. Within a well developed vertical plume there is a net, though relatively small, mean updraft ($w > 0$), while outside of the plume w will be zero or negative. Therefore if $\bar{u}$ is significantly above zero, the mean horizontal flow will act to continuously move parcels downstream replacing them with air having a vertical velocity less than or equal to zero. Under windy conditions, for each successive parcel: $-w \frac{\partial w}{\partial z} \lesssim 0$ and therefore $\frac{\partial w}{\partial t}$ is less than what it would be if $-w \frac{\partial w}{\partial z} > 0$. As $\bar{u} \to 0$, each successive parcel will rise into the wake of the previous parcel such that $-w \frac{\partial w}{\partial z} > 0$. Therefore, $\frac{\partial w}{\partial t}$ will be larger than in the case with a significant mean wind, and the mean in plume updraft will therefore be proportionally higher.

Another ramification of the observed rapid decrease in temperature within a plume is the probability that condensation processes may contribute significantly to the plume particulate concentrations. A plausible scenario by which this could happen is the following. Heat radiated to the unburned fuel in the vicinity of the flame zone will be utilized - at least in part - to evaporate moisture, sap and other material with significant vapor pressures at temperatures greater than say 50°C. Given the type of fuel, significant distillation of medium and long chain hydrocarbons should occur. Not all of the distillates, especially for front fires, will pass through the flame zone as they rise and little to no oxidation of these would be expected. Of those that do enter the flame, oxygen deficiencies and relatively low flame temperatures may prevent total oxidation of at least some of them. It is therefore expected that considerable masses of hydrocarbons will be emitted from the active fire zone in a gaseous phase and only partially oxidized. With the rapid cooling due to both entrainment and radiational losses immediately above the fire zone, most of the large molecule compounds will condense adding a large number of liquid droplets to the particulate load in the plume. As the material continues to rise and diffuse, continued entrainment of ambient air will lower the average gas phase mixing ratio for each compound, in turn reducing the ambient vapor pressure over the liquid phase material. Therefore it is expected that a slow re-evaporation of these droplets would be a likely occurrence. Evidence that this scenario is more than plausible is presented in the next section.

D. Particulates:

In this section, the particulate data are summarized in a variety of ways to emphasize different aspects of fire emissions. The most difficult problem encountered in attempting to interpret the results of the plume penetrations is that no two fires are exactly alike in terms of the fuel status and the ambient meteorological conditions. Obviously the effluent concentrations measured in any plume is primarily dependent on the source strength and the mean wind speed. As discussed in a previous section, the plume behavior is in general sensitive to wind speed. The source strength depends on the type of fire, rate of fuel consumption, and the flame temperatures (the hotter the flame temperatures, the lower the particulate emissions). The flame temperatures in turn depend on fuel moisture content, fuel density and oxygen supply, stubble height, fuel matting and compaction, separation between maximum fuel concentration and the ground, etc. With such a large number of independent variables, exact duplication of all variables among large numbers of fires is not to be expected. Therefore, relative trends found between sets of fires which are nearly alike are more significant than absolute values for any one fire or averages of absolute values for all fires.

Finally, for front fires, the size of the field burned also affects measured concentrations. This is because the scale size of the source implies a scale size for the plume generated. Since entrainment and frictional dissipation depend on the surface area of the plume-air boundary but buoyancy is volumetric, the larger the plume diameter the more efficient the net plume rise for a given buoyancy. Therefore, at low to moderate wind speeds, the larger the fire, the more likely it is to form a nearly vertical columnar plume. However, at wind speeds high enough to suppress vertical plume formation, the larger the field, the larger will be the separation between the active and smoldering subsources with time. Therefore, as the burn progresses, fewer smolder emissions will be entrained into the active fire front so that they are neither oxidized further nor injected into the more buoyant plume.

The summaries presented in this section are in terms of particle concentrations and relative size distributions for particles greater than 0.4μ in diameter. Table 2 summarizes all available data on average concentrations of particles measured between 30 and 300 meters above terrain. The average measured concentration by number for the background samples, the net from backfires and the net from non-backfires are shown. The gravimetric concentrations were calculated from the observed size distribution and assumed particle densities. The standard deviations for each sample are also shown. For front fires, samples of emissions from the active plumes, smolder areas and spread plumes if available from a single fire, are averaged and counted as one sample in Table 2.

The rather high standard deviations in each category is indicative of the rather large differences in the average particulate concentrations in plumes of a given fire type. For example, the concentrations from a backfire on one day may be comparable to the emissions from a front fire on another day. For this reason, comparison of the average figures in Table 2 to assess the effects of front firing versus backfiring would be misleading.

A better estimate of the degree to which emissions are reduced by backfires is obtained if matched pairs of fires are evaluated. As discussed above, the source strength is a function of fuel state and ambient conditions. Therefore, emission comparisons between individual sets of one back and one front fire within the same field and both burned within about an hour's time should minimize bias caused by variation in the independent variables. Averages of the individual ratios of front fire to backfire emissions for six sets of fires are presented in Table 3. Also shown is a ratio of the fuel consumption rates.

The fuel consumption ratios in Table 3 were calculated from ground data on the amount of fuel in the field and the duration of a burn. For backfires the flame front usually advances slowly and steadily with a fairly constant, easily determined fuel consumption rate. It should be noted, however, that the fuel consumption rates are difficult to establish accurately for front fires. With front fires, the rapid advance of the flame front and the slower burning smolder areas results in a nonuniform fuel combustion rate which reaches a peak when both the flame front and smoldering regions are active and decreases after the flame front has traversed the field. The estimates of fuel consumption rates for front fires, for the purposes of Table 3, are based on the qualitative information that the smoldering areas are essentially expended in about 3 times the life time of the flame front.

TABLE 2

Average concentrations of particulates greater than 0.4μ in diameter and their standard deviations for all available data. All samples were obtained between 30 and 300 meters above terrain. Fire data are net plume concentrations.

Type of Sample	Sample Size	Concentrations: Particles m^{-3}	Concentrations: $\mu gm\ m^{-3}$ (Calc.)
Background ave.:	25	6.60×10^7	678
Std. Dev.:		8.50×10^7	665
Backfires ave.:	8	1.90×10^7	419
Std. Dev.:		2.60×10^7	471
Front & perimeter ave.:	11	4.810×10^7	1329
Std. Dev.:		5.50×10^7	2946
Pile Fires ave.:	2	8.10×10^7	-
Std. Dev.:		102.0×10^7	-

TABLE 3

Average ratios of front to backfire emissions and fuel consumption determined from 6 sets of nearly simultaneous pairs:

Ratio of Number Concentrations	5.5:1
Ratio of Gravimetric Concentrations (Calc.)	7.3:1
Ratio of Fuel Consumption Rates	4.6:1

Given these uncertainties several conclusions can still be drawn from the information in Table 3. First, the net plume number concentrations are about 5.5 times larger in front fire plumes than backfire plumes. The estimated gravimetric concentrations are 7.3 times higher, which means that the number median diameter is larger for front fires or that more soil particles are contained in the plume or both.

In terms of total particulate emissions (not concentrations) per unit of fuel burned, the two methods are nearly comparable with backfires apparently producing 10-20% fewer particles (> 0.4 μ in diameter) per unit of fuel than front fires. In gravimetric units, backfires appear to be nearly 50% cleaner per unit of fuel burned, which agrees with laboratory results (Miller et al, 1973).

The average size distribution, by number, of the samples is shown in Table 4. The data are presented as cumulative averages for background samples, and front, back and pile burn samples for which the net fire contributions are available. The standard deviations and sample sizes are also given. What the Table clearly shows is that for other than pile fires, over 90% of all particles larger than 0.4 μ are less than 1.3 μ in diameter. The summarized data indicates that the number median diameter is close to the detection threshold size. It is therefore safe to assume that our 0.4 μ threshold precludes detection of the true number density since the number of particles less than 0.4 μ is probably very large.

Although this may appear to be a serious flaw in the experiment, several arguments can be made in defense of the measurements reported. First, the real time counting of particles less than 0.4 μ diameter would require instrumentation too bulky, heavy or power hungry for use in even a twin-engined light aircraft. To evaluate size distribution at sizes less than 0.4 μ in diameter, electron microscopy is required. However, if most of the smaller particles are hydrocarbons (as indicated below) then the high vacuum needed for electron-microscopic analysis would probably result in the evaporation of these droplets producing only questionable results. In addition, the two major causes for concern regarding particulate emissions from agricultural burning are visibility degradation and lung impaction. Since both of these effects are most pronounced for particles between 0.4 and 4 μ in diameter, the measurements are appropriate for discerning these particles.

Looking at specific relations indicated by Table 4, it is rather obvious that the average backfire size distribution is essentially the same as the average background distribution. Surpisingly the average front fire appears to have a higher percentage of sub-micron particles than does the average backfire. There are several plausible explanations for this. For one, the signal to noise ratio for backfires is generally low because of their low emission rates. Therefore, small percentual errors in the size distribution in either the background or total plume data will result in large percentual errors in the net backfire size distributions. Assuming however that this is a significant trend, another explanation could be that backfire emissions may consist predominately of particles less than 0.4 μ so that our backfire measurements are really in the wings of the distribution. For front fires the maximum emissions may be close to 0.4 μ so that we are measuring a much larger fraction of the total emissions and they have their greatest effect on the smallest size interval. A third explanation may be that more complete combustion occurs in backfires with the result that fewer distillates are emitted that can later condense. Since the condensation products associated with front fires would be expected to occur in a spectrum of sizes and these

TABLE 4

Average and standard deviations for the cumulative size distribution (by number) of particles > 0.4 μ diameter and less than stated size - by type of fire.

	% less than stated size (μ diameter)						
Data	0.7	1.3	2.7	5.3	10.6	20	# in sample
Ave Bkgnd	69.0	90.8	97.2	99.0	100	100	12
σ	13.8	4.9	1.8	0.7	<0.5	0	
Front Fires	76.8	96.0	97.8	99.0	99.9	100	8
σ	21.4	5.6	3.0	2.2	0.2	0	
Backfire	65.4	90.3	97.6	99.6	100	100	6
σ	27.0	14.0	2.8	0.3	0	0	
Piles	51.5	85.1	94.7	98.5	100	100	2 samples of each of
σ	28.4	10.3	3.5	1.7	0	0	2 fires

are in addition to effluents from more complete combustion, the fivefold greater front fire emissions could easily add 17% more particulate to the smallest size range.

Pile burns appear to have the largest median diameters.

From the number-size distribution and presumed densities, cumulative mass distributions were calculated. These are summarized in Table 5. Obviously, the r^3 dependence of the mass calculation favors the larger sizes in the distribution. From these calculations, mass median diameters for all particles greater than 0.4μ are: background ~ 7μ, front and backfires ~ 9μ. Due to the small sample available, similar data for pile fires is not included. Again, it should be emphasized that these gravimetric calculations are crude approximations because of the assumed densities and because of their very high sensitivity to the larger sizes which in turn have the smallest number concentrations and therefore the lowest statistical significance.

A comparison of non-backfire subsources is made in Table 6. The number of samples represented is small because matched sets of data from individual fires are necessary to evaluate trends independent of burn conditions. The most obvious characteristics of the comparison are that the relative sizes of particles emitted from the active flame area are significantly smaller than for the smoldering areas. The size distribution within the aged plume is rather surprising in that one would expect this to approach the background distribution (Table 4) whereas this set of plumes shows very high relative numbers of 0.4 to 0.7μ particles. Since an aged plume must include some of the smolder emissions, the implications are that a) the smoke ages in such a way that the size distribution shifts toward the smaller ranges and b) the background particulate concentrations are only partially due to agricultural burning.

TABLE 5

Average cumulative % of particles by mass less than stated size - calculated from the number size distributions for particles > 0.4μ diameter - and the standard deviation (σ) within the population.

Data	% of particles (mass) less than stated size						
	0.7	1.3	2.6	5.3	10.6	20	# in sample
Bkgnd	1.5	4.2	14.7	36.4	88.2	100	18
σ	2.1	5.1	16.8	55.6	27.0	0.1	
Front Fires	0.7	3.3	5.8	27.0	53.0	99.9	7
σ	0.6	2.3	4.5	31.7	33	0.2	
Backfires	0.15	0.6	3.5	22.3	60.4	100	4
σ	0.05	0.4	2.3	22.7	40.8	0	

Estimated MMD:

Bkgnd ~ 7μ
Front Fires ~ 9μ
Backfires ~ 9μ

TABLE 6

Comparison of cumulative size distributions (by number) from the active, smoldering and aged plumes of front and pile fires.

Source type	% by number less than stated size 0.7	1.3	2.6	5.3	10.6	20	sample size
active	87.1	99.0	99.7	99.8	100	100	5
smolder	54.9	85.4	93.3	96.6	100	100	4
aged	93.2	94.0	100	100	100	100	4

If this apparent size shift with aging is true of all fires and if most of the smolder products are in fact liquid hydrocarbon condensates, then the evidence presented in Table 6 would appear to support the aging by evaporation hypothesis presented in the previous section. It is, however, also quite possible that the observed size shift may be the result of chemical or photochemical reactions. Since photochemical reagents are not totally absent in the area studied, some reactions of this type probably do occur.

Data on the relative plume concentrations between subsources is, perhaps, more significant than the relative size distributions. The average concentration ratios (by number) for sets of smoldering and active zones from individual fires is 4.4:1. This verifies the qualitative visual observations reported above that most of the smoke from a front fire is emitted by the smoldering areas. This accounts for at least part of the excess emissions from front and pile fires as compared with backfires.

The analysis of size distributions in terms of angular and amorphous particles was done primarily to allow reasonable estimates of gravimetric concentrations. However, in view of the results discussed above, some interesting trends are apparent in the relative proportion of amorphous (i.e. liquid) particles in each size range.

Average values of this proportion, in percent, are presented in Table 7 for various sample types. The values for the smallest size range in any individual sample may be inaccurate since considerable subjective judgement is required by the microscope operator to make these distinctions for the very small particles. However, since operator bias is probably random, averages over many samples are probably fairly accurate. Furthermore, high volume impactor samples taken at ground level supports the data in Table 7

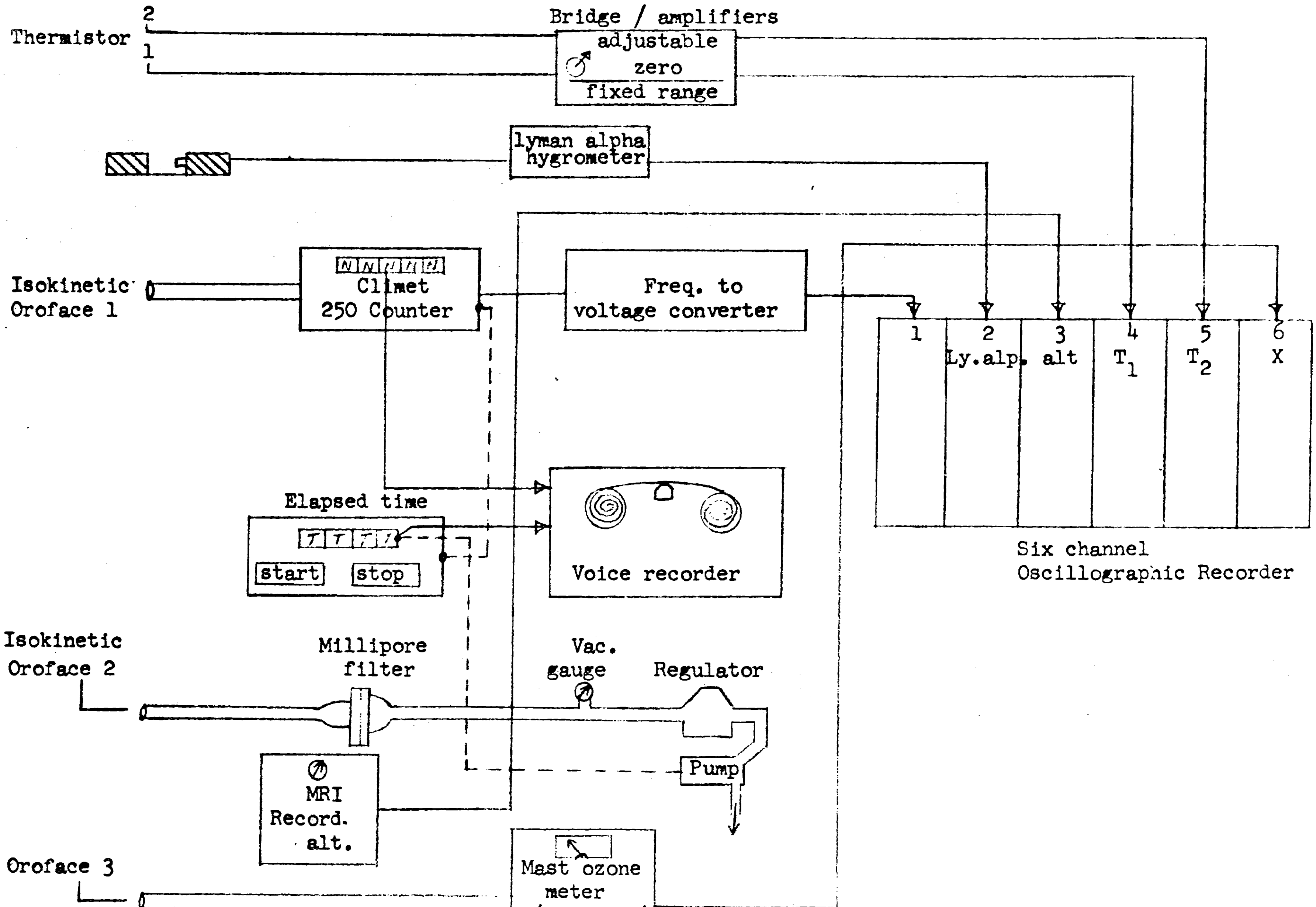
TABLE 7

Average percent of particles within each size interval that are amorphous in form:

Source type	Sample size	0.4-0.7	0.7-1.3	1.3-2.6	2.6-5.3	5.3-10.6	>10.6	Size μ diam.
Bkgnd	19	76	74	41	2	0	0	
Front (active)	8	92	60	21	0	0	0	
Front (smolder)	4	93	72	20	2	7	0	
Aged	2	95	5	0	0	0	0	
Back-fires	5	98	49	21	17	0	0	

in that most of the material collected in the submicron size range has a tarry appearance and is cloroform soluble. Therefore, the relative proportions shown in Table 7 are believed to be realistic. The data indicate that the majority of particles less than 1.3 μ in diameter in the free air and in smoke plumes are liquid hydrocarbons. We do not have firsthand knowledge of the types of compounds present in this group. However, from the laboratory studies of Boubel, et al (1969) and by Darley, et al (1966) some plausible estimates can be made. Emissions from burning grass and straw are in the order of 15 lbs of particulate and 10 lbs of unburned (gaseous phase) hydrocarbons per ton of fuel burned. Since these data are from stack samples at temperatures much higher than our samples, but considerably lower than the flame temperatures, at least some of this particulate material should be unburned hydrocarbon. Since they do not report on the physical or chemical characteristics of the particulate collected, we do not know how much, if any, of this material is what we have called tarry hydrocarbons. Except for ethylene and olefins, the compounds comprising the unburned gaseous hydrocarbons are unkonwn. Presumably a considerable portion of the laboratory measured particulate and the gaseous phase hydrocarbons are fairly large molecules, like the olefins, which have boiling points lower than temperatures in the flame region, but considerably greater than free air temperatures. In addition to a simple distillation-condensation process, these compounds would be expected to undergo at least partial oxidation, which would yield substances like aldehydes and keytones. This class of compounds, with the exception of formaldehyde and acetaldehyde have boiling points well above 20°C.

It therefore seems reasonable to conclude that most of the particles in smoke plumes less than 1.3 μ in diameter, which in turn are most of the particles in the plume, are olefins and other medium and large molecule hydrocarbons. Some of these are undoubtedly oxidized to a variety of secondary compounds including some aldehydes. The vast majority of particles greater than 1.3 μ appear crystalline and are presumed to be predominantly silica, other soil minerals and ash.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1
Bridge / amplifiers
adjustable
zero
fixed range
lyman alpha
hygrometer
Isokinetic
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Climet
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Freq. to
voltage converter
1
2
Ly.alp.
3
alt
4
T1
5
T2
6
X
Six channel
Oscillographic Recorder
Elapsed time
start
stop
Voice recorder
Isokinetic
Oroface 2
Millipore
filter
Vac.
gauge
Regulator
Pump
MRI
Record.
alt.
Oroface 3
Mast ozone
meter
(optional)

Figure 1

Figure 2 Sketch of a well developed fire plume in the presence of no ground level wind and an elevated inversion.

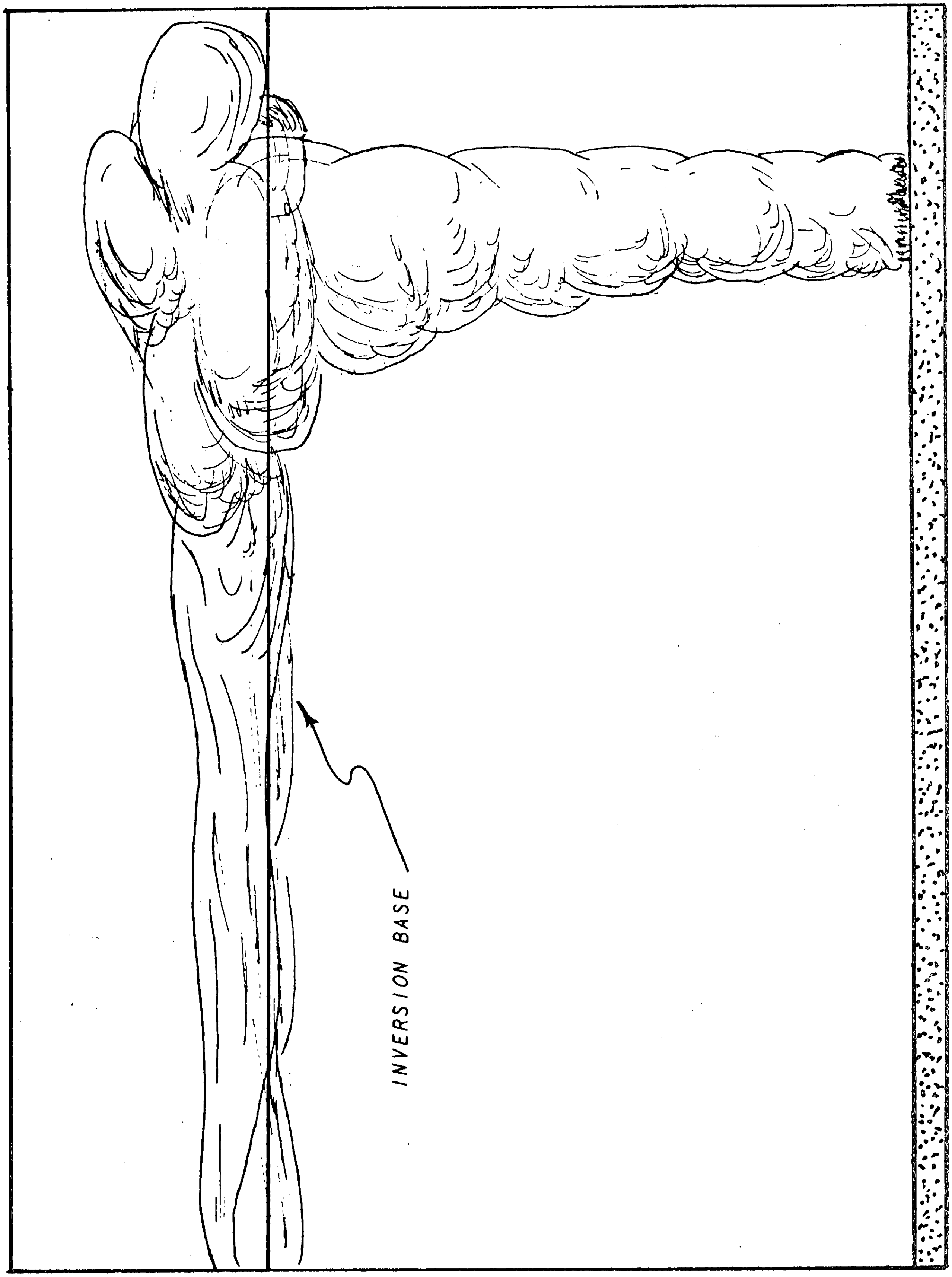

Figure 2

Figure 3 Sketch of the form of a front fire plume with moderate wind speed showing the two subsources: the active flame front and the smoldering area.

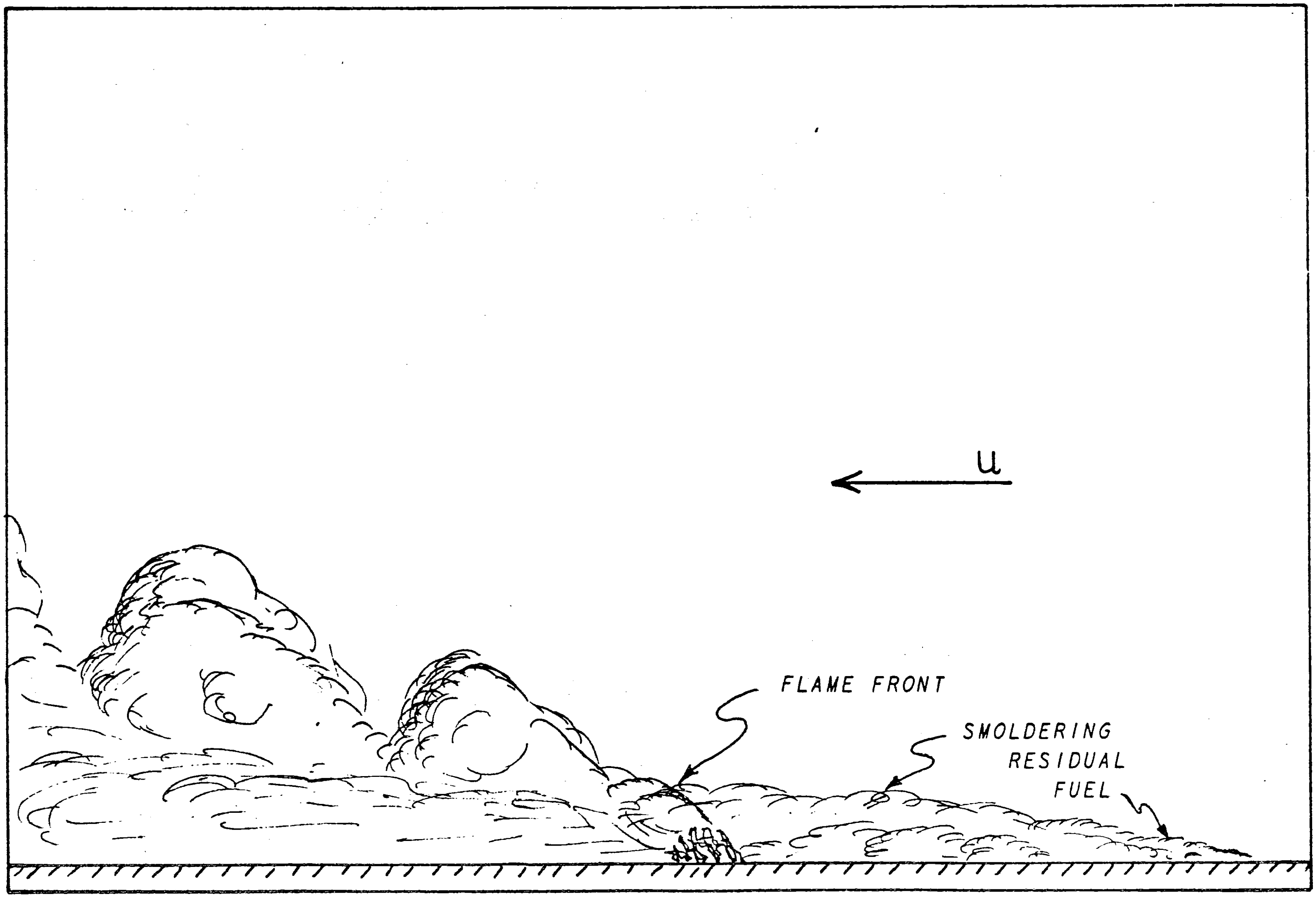

Figure 3

Figure 4 Sketch of the ring vortex structure characteristic of buoyant parcels, shown as a side view of the streamlines.

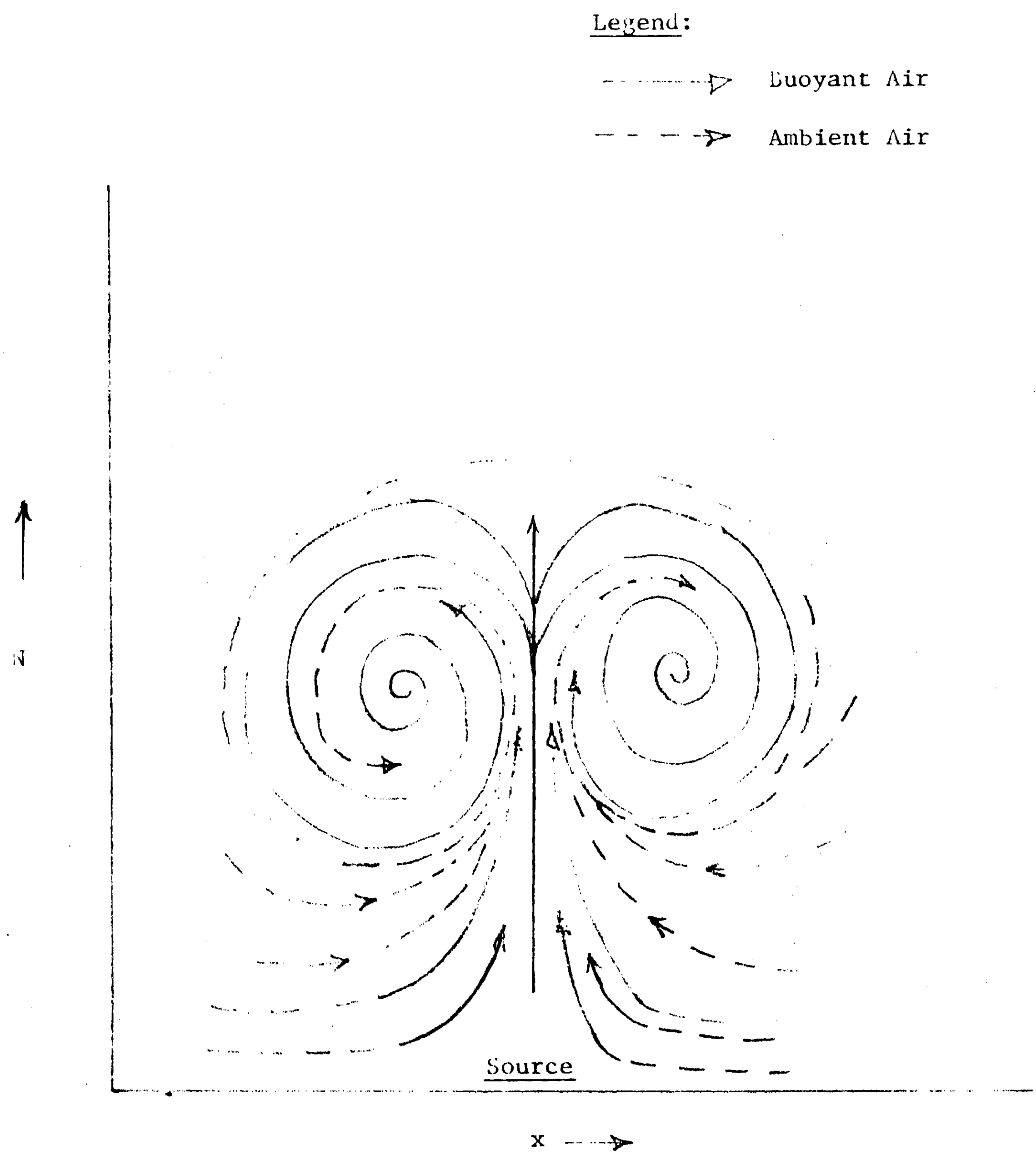

Figure 4

APPENDIX A

SOUNDING DATA

Plots of the measured variables as functions of height are presented for 16 soundings taken during the course of work reported in this document. All soundings include temperature data, nearly all include moisture data and some include wind and particulate concentration data. The plots are arranged sequentially in chronological order with the date and local time noted in the lower left corner of the display. An index to the date and time of each is given below.

Altitude was obtained using an MRI recording altimeter accurate to ± 15 ft. MSL. Altimeter settings were verified before and after each flight and interpolated linearly through the sample period.

Temperature data were measured with a fast response thermistor accurate to ± 0.1°C. Note that the plotted temperature scale may vary from plot to plot.

Absolute humidity was measured using an EMR Lyman-alpha humidiometer mounted in the free air stream under the wing. Its accuracy is approximately $\pm 0.25 \times 10^{-6}$ gm/cm^3. As with the other variables, the absolute humidity scale may vary from plot to plot.

Wind data were obtained from double theodolite pibal measurements. These are plotted using the normal convention of north at the top of the page and each half barb equal to 5 mph ($\approx$ 2.5 m sec^{-1}) and each full barb equal to 10 mph ($\approx$ 5 m sec^{-1}).

Particulate data were obtained using a Climet 250 particle counter. The July 1972 data represent 36 second averages, which at a normal rate of climb represents a layer 55 m (180 ft.) thick. Post July 1972 data are instantaneous concentrations. The concentrations given are the number of particles per cubic meter of air greater than 0.4 μ in diameter. Note that the scale for the particle concentrations may vary by orders of magnitude between diagrams.

Index to Soundings

#	Date	Local Time
1	8-10-71	1043
2	8-10-71	1200
3	11-5-71	1500
4	11-5-71	1630
5	7-31-72	1045
6	7-31-72	1120
7	10-25-72	1400
8	10-27-72	1540
9	11-1-72	1435
10	11-27-72	1420
11	11-27-72	1500
12	3-27-73	1435
13	3-29-73	1055
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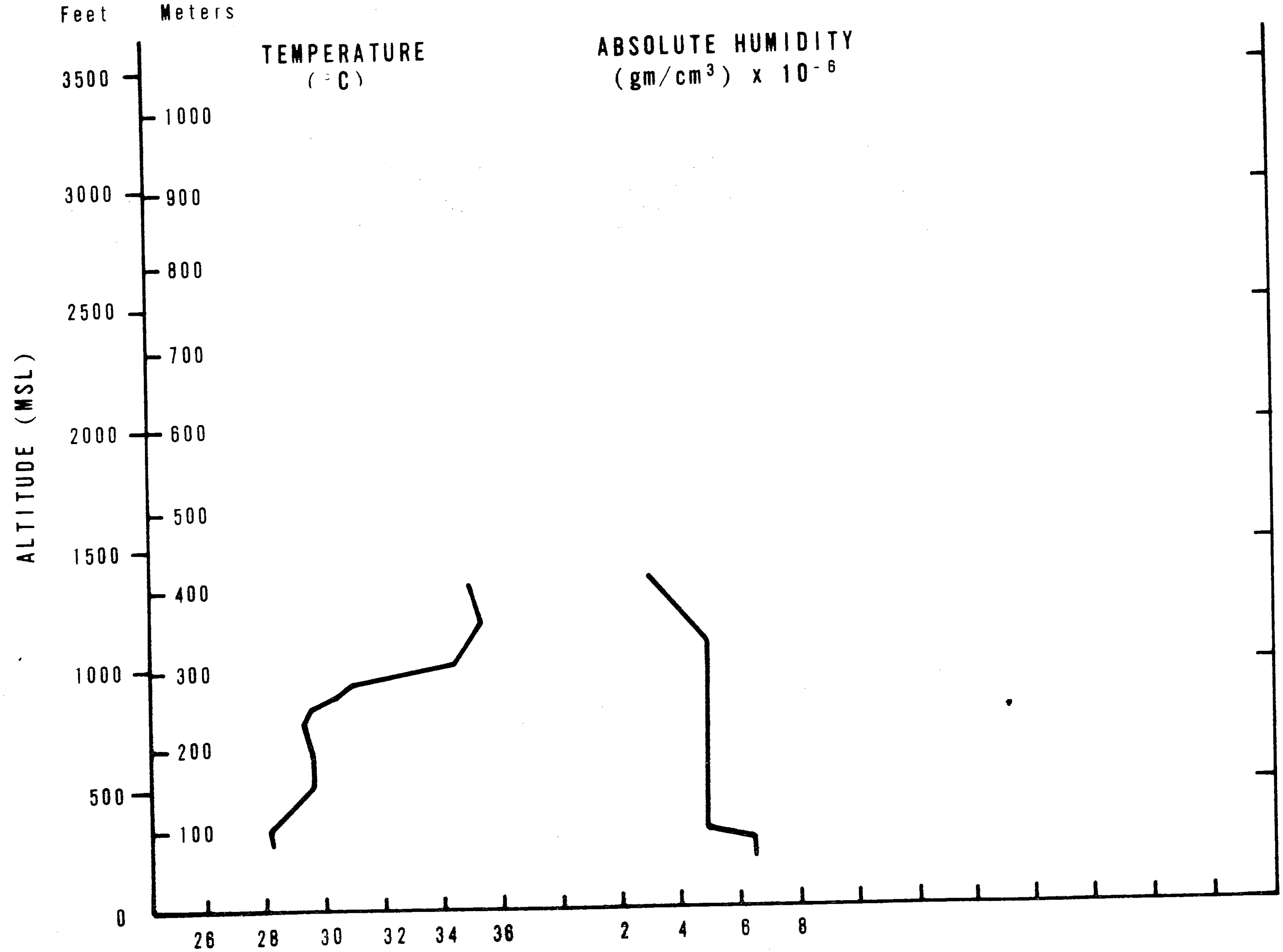
Feet
Meters
TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
ALTITUDE (MSL)
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2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
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28
30
32
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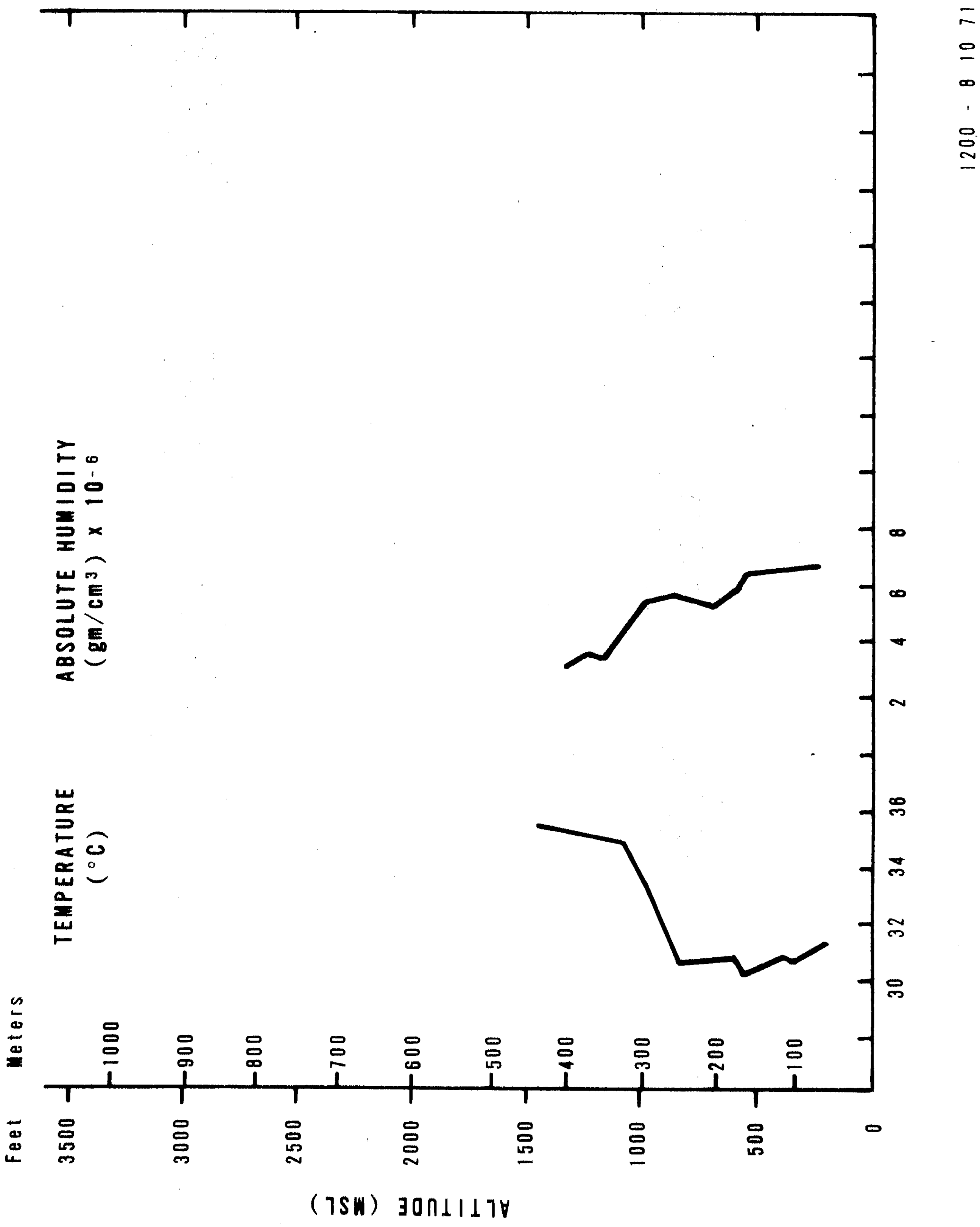
36
2
4
6
8

1043 - 8/10/71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(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10-6
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6
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Meters
1000
900
800
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600
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ALTITUDE (MSL)
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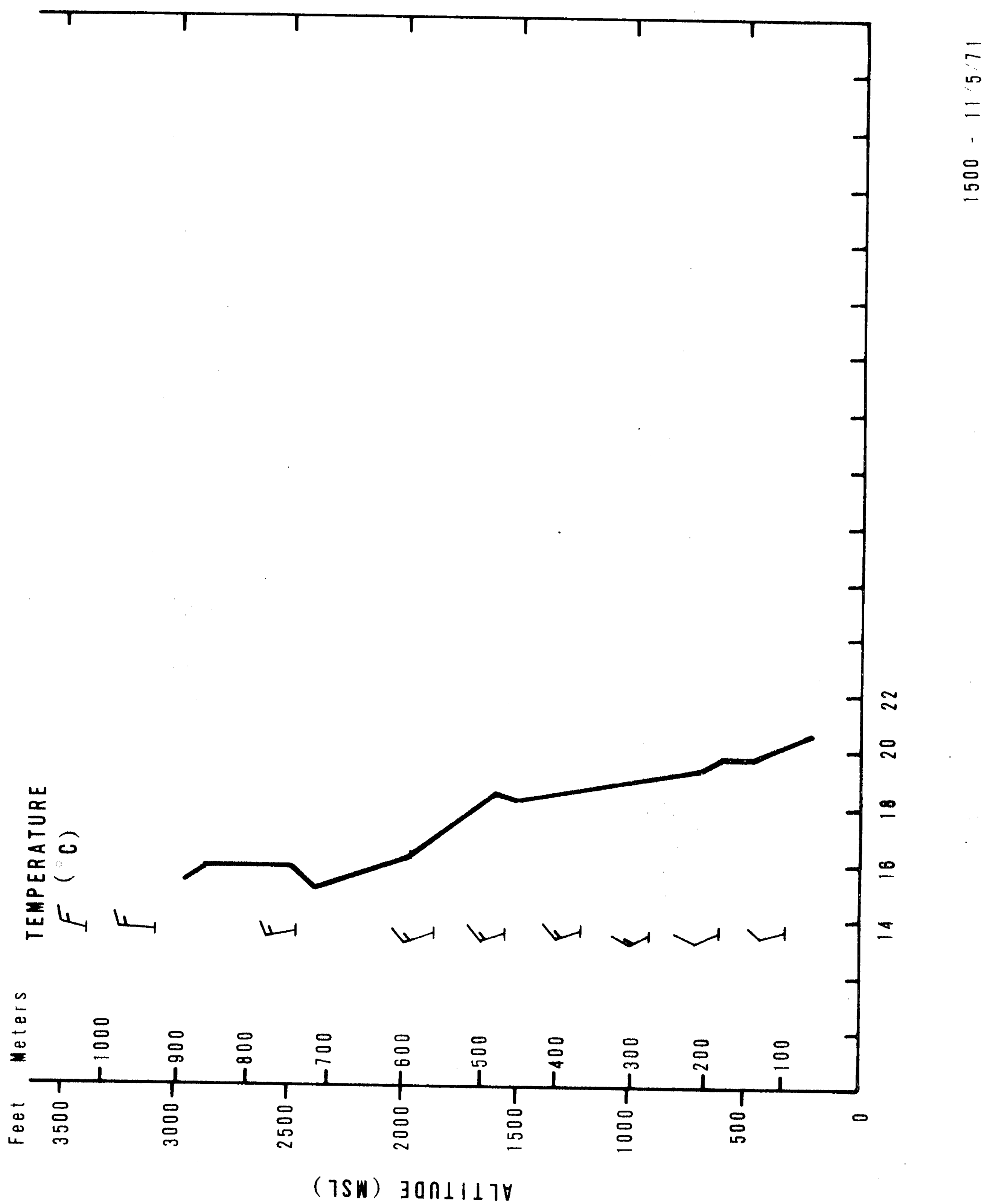
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TEMPERATURE
(°C)
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16
18
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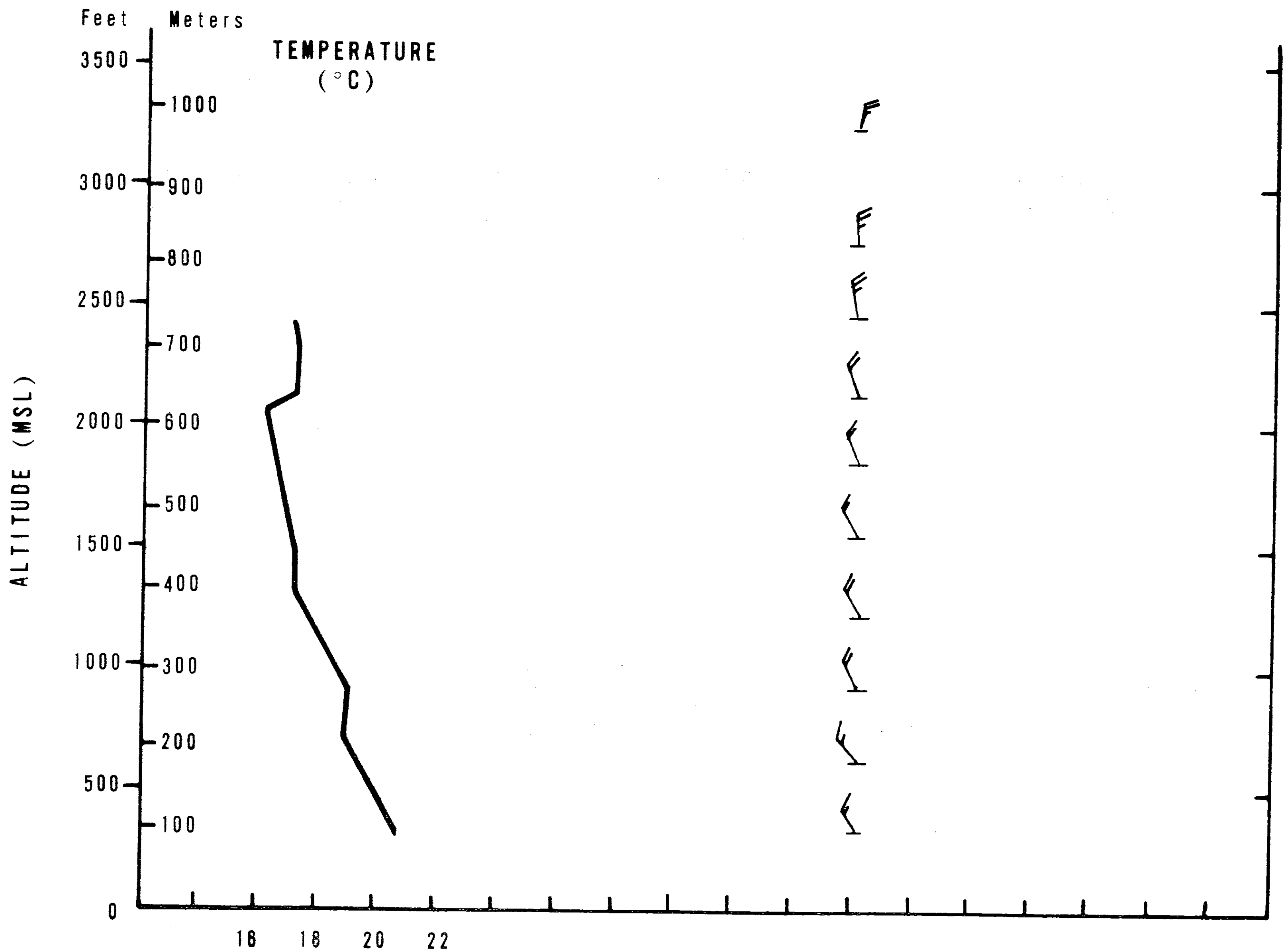
22
ALTITUDE (MSL)
1500 - 11/5/71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TEMPERATURE
(°C)
ALTITUDE (MSL)
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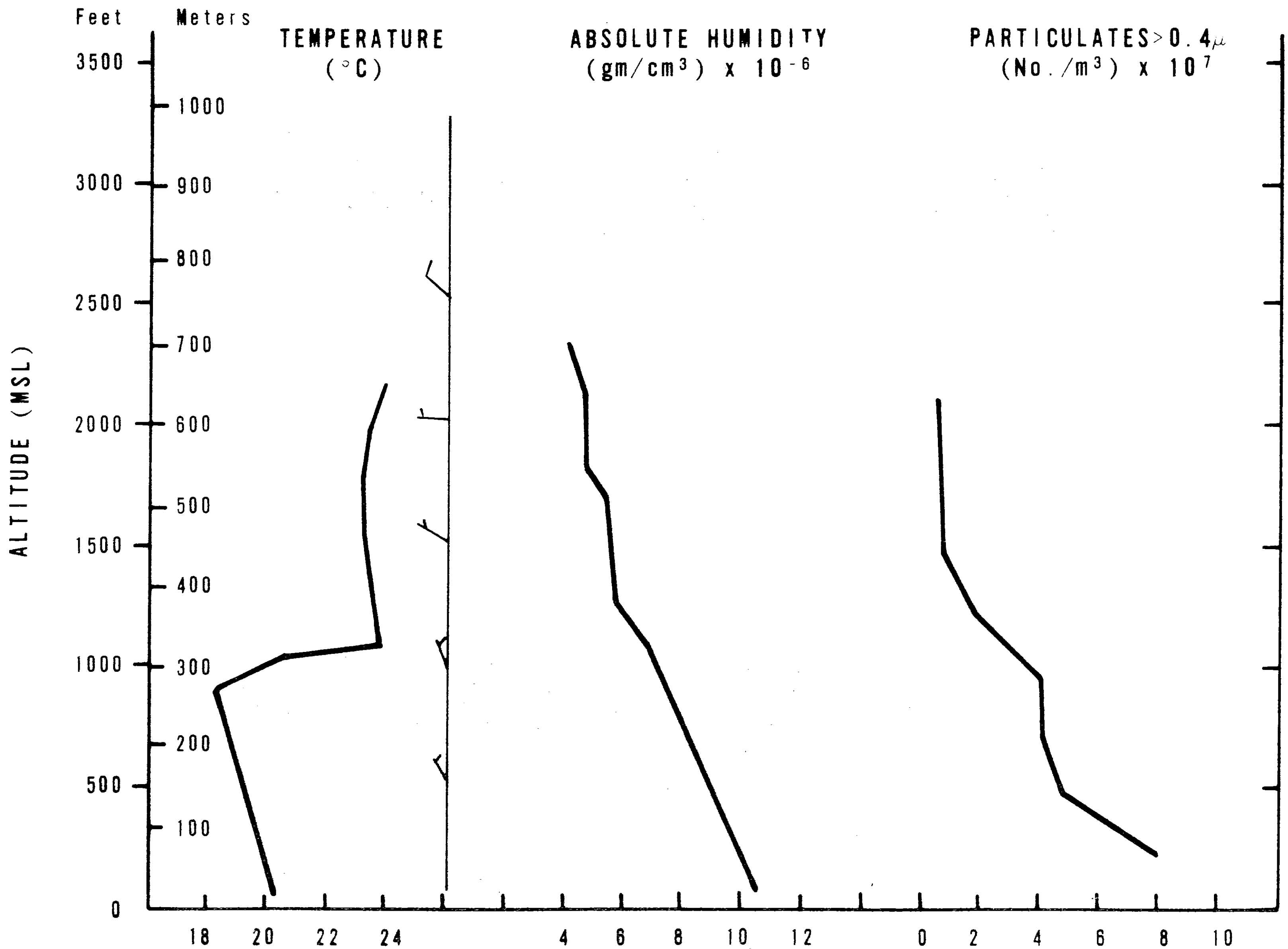
1630 - 11/5/71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Meters
TEMPERATURE (°C)
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PARTICULATES>0.4μ (No./m³) x 10⁷
ALTITUDE (MSL)
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3000
2500
2000
1500
1000
500
0
1000
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200
100
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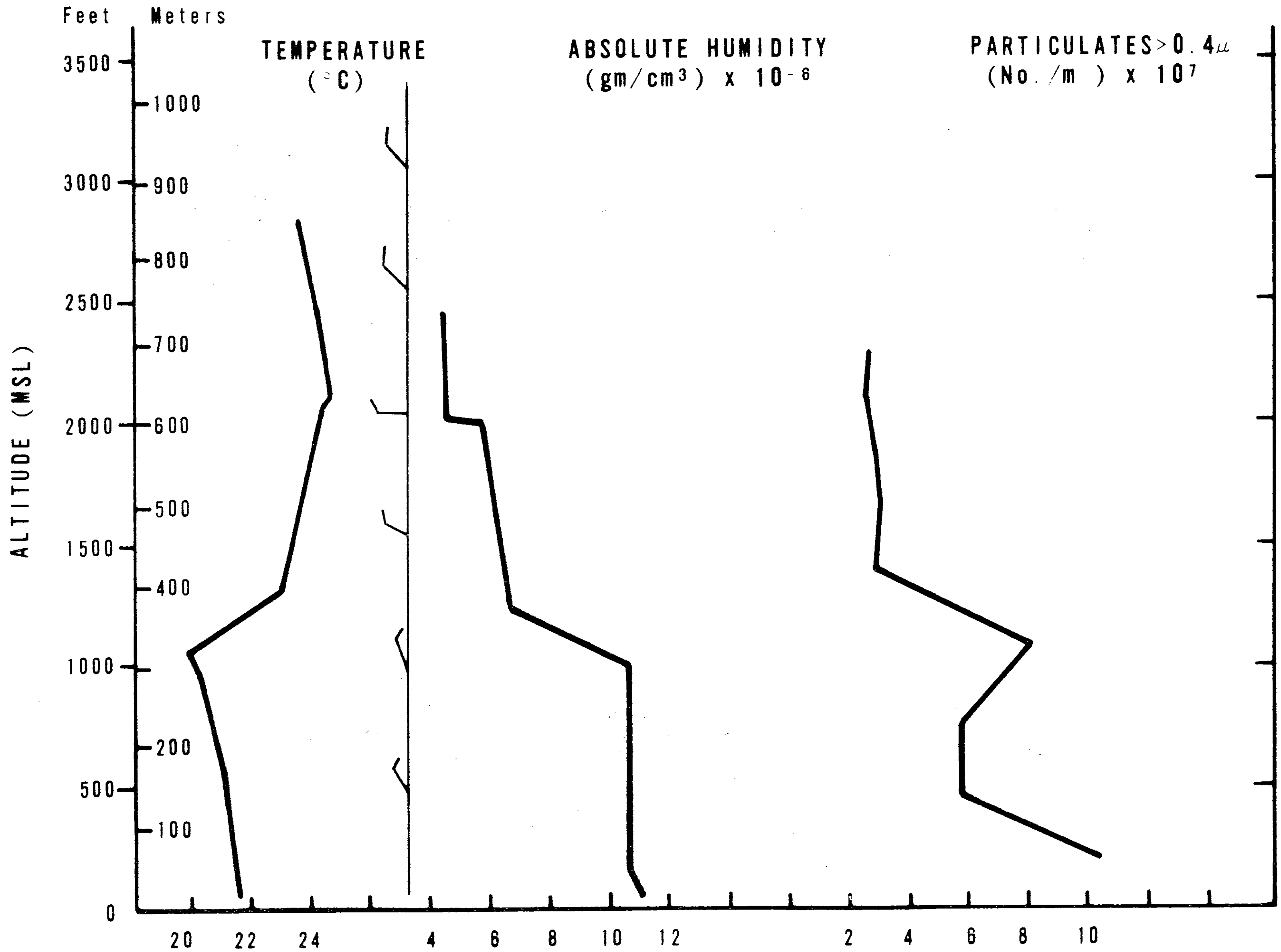
0 2 4 6 8 10

1045 - 7/31/72


Feet
Meters
TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10-6
PARTICULATES>0.4µ
(No./m) x 10⁷
ALTITUDE (MSL)
3500
3000
2500
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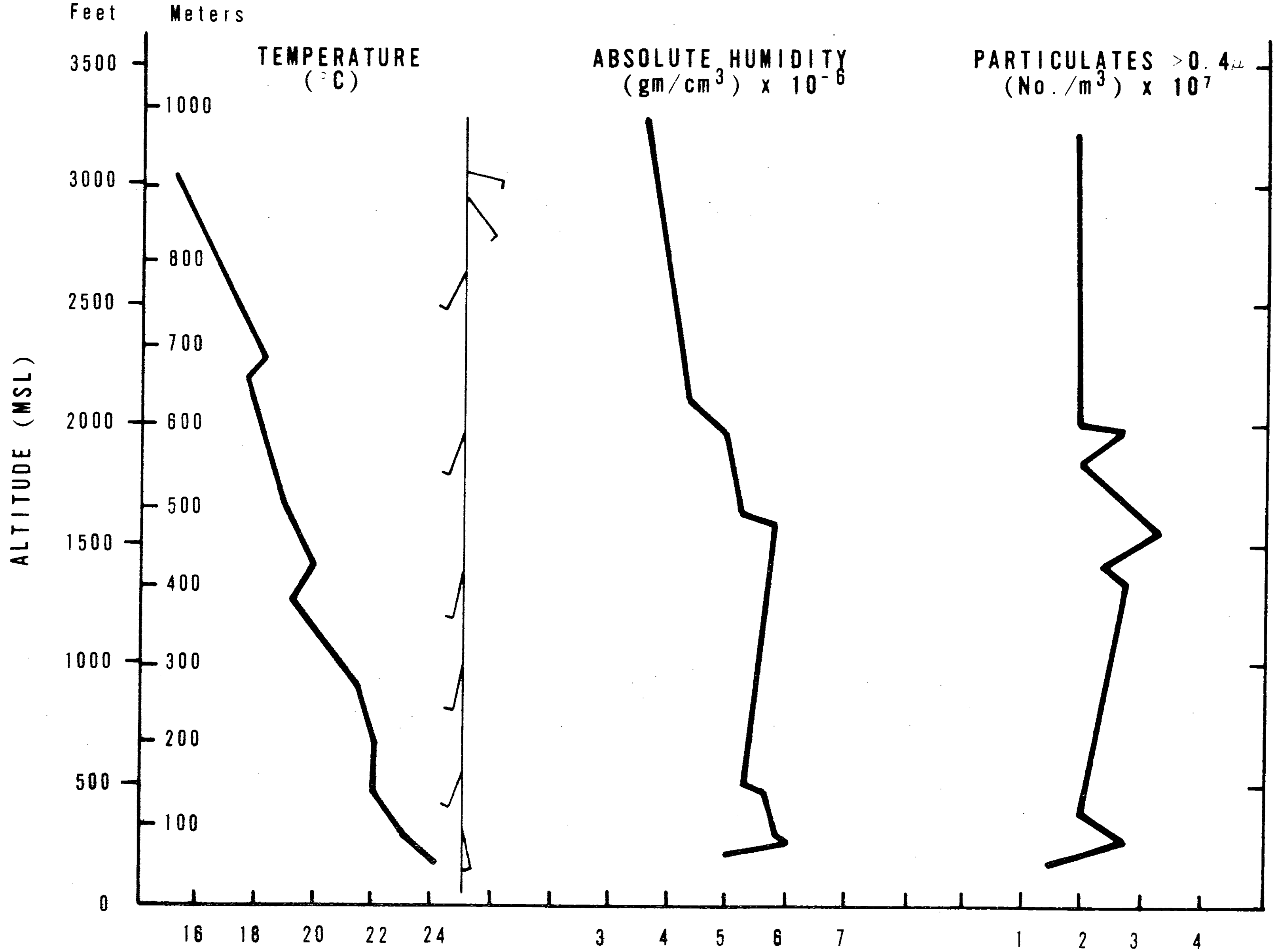
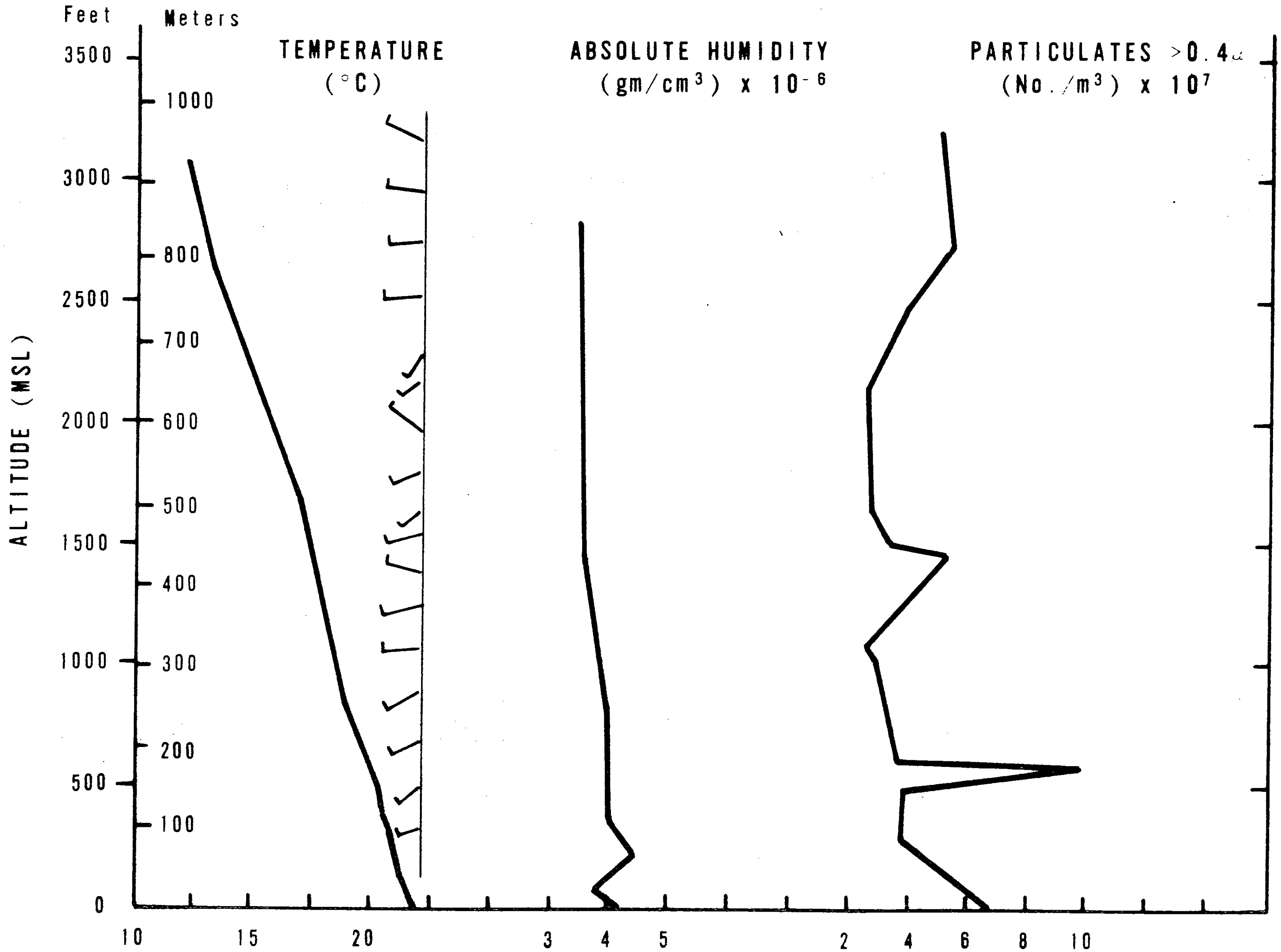
8
10

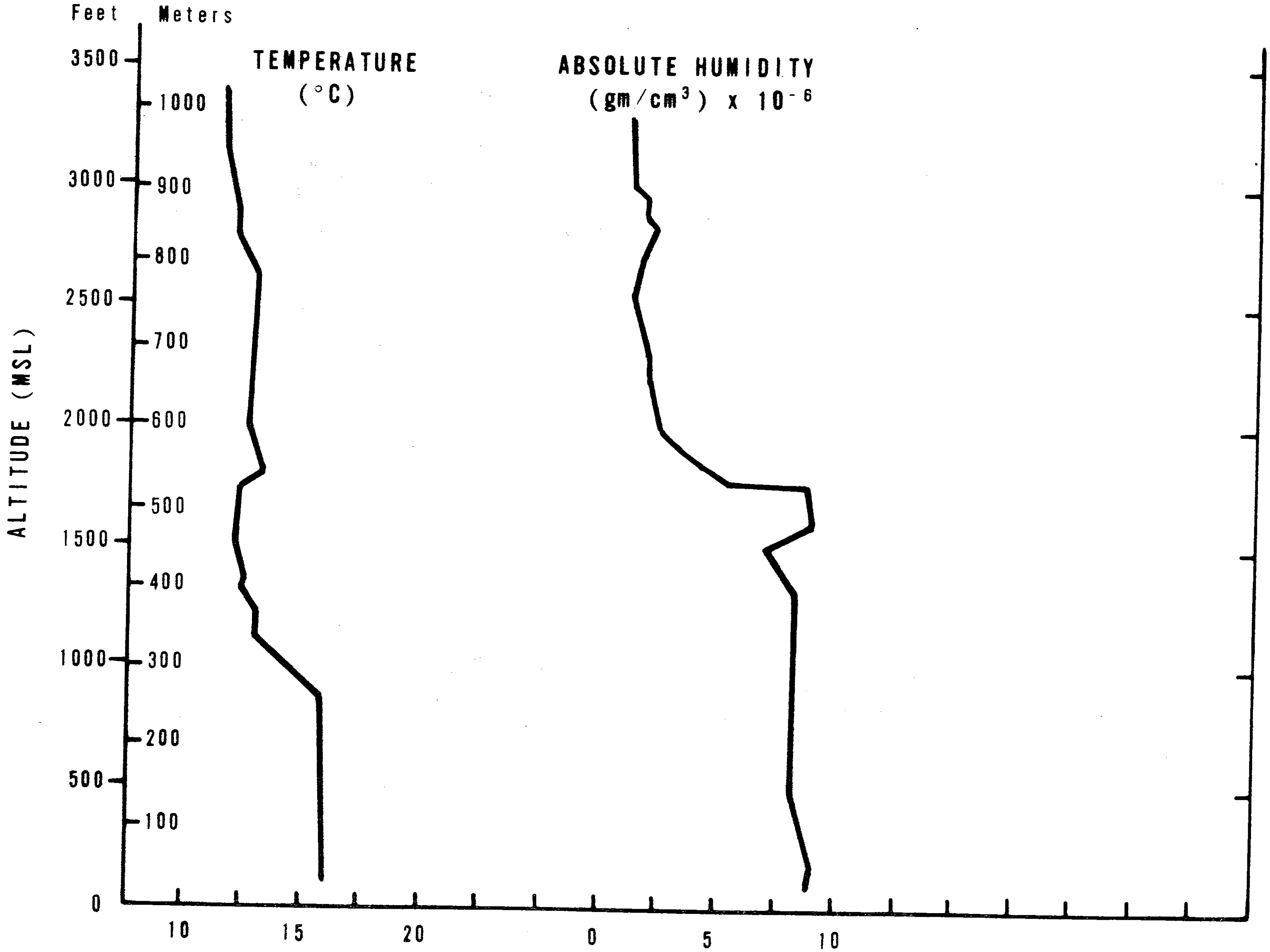
1120 - 7/31/72


Feet
Meters
TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
PARTICULATES >0.4μ
(No./m³) x 10⁷
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
1000
800
700
600
500
400
300
200
100
16
18
20
22
24
3
4
5
6
7
1
2
3
4

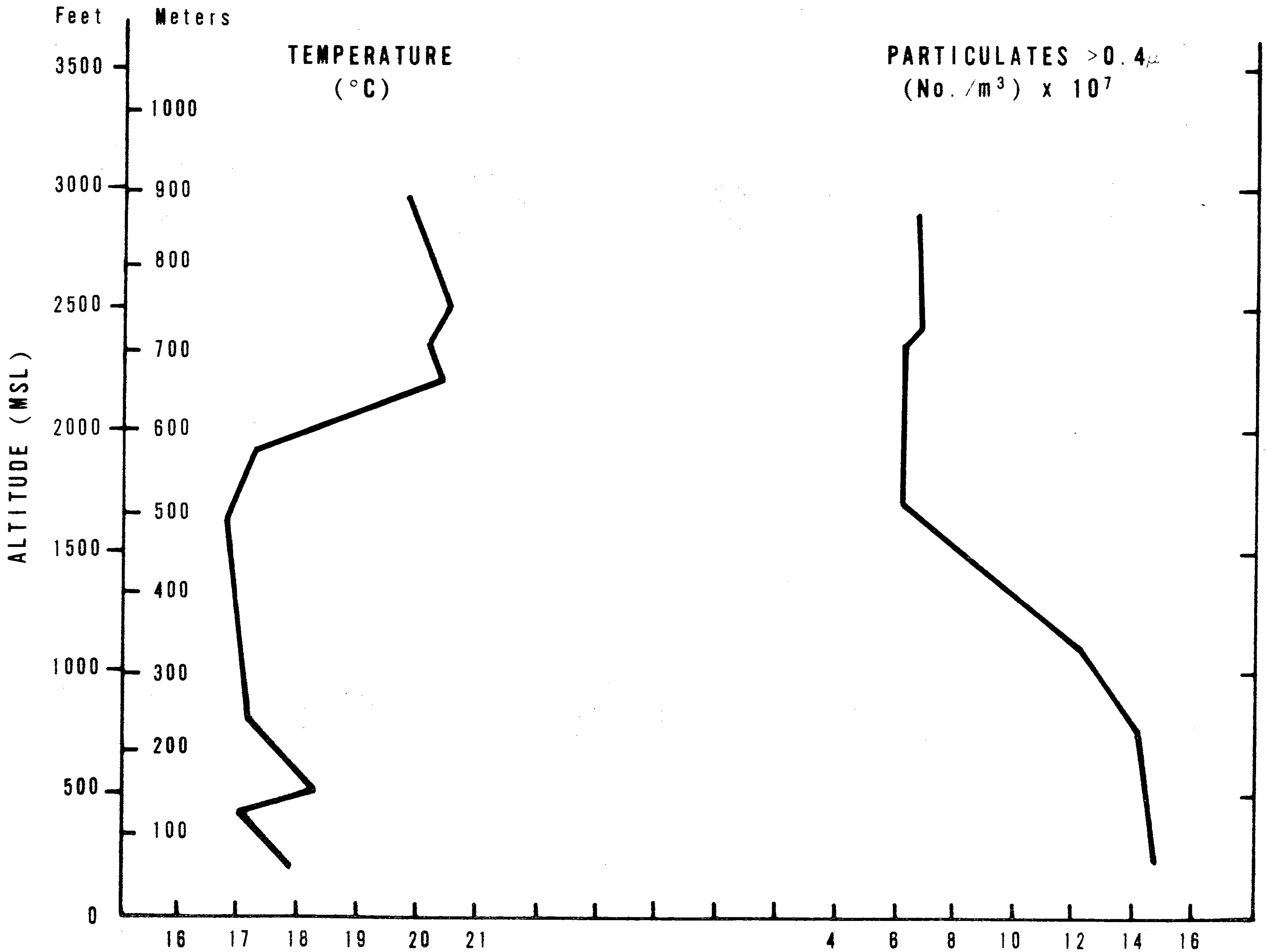
1400 - 10 25 '72


Feet
Meters
TEMPERATURE (°C)
ABSOLUTE HUMIDITY (gm/cm³) x 10⁻⁶
PARTICULATES >0.4μ (No./m³) x 10⁷
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
1000
800
700
600
500
400
300
200
100
10
15
20
3
4
5
2
4
6
8
10

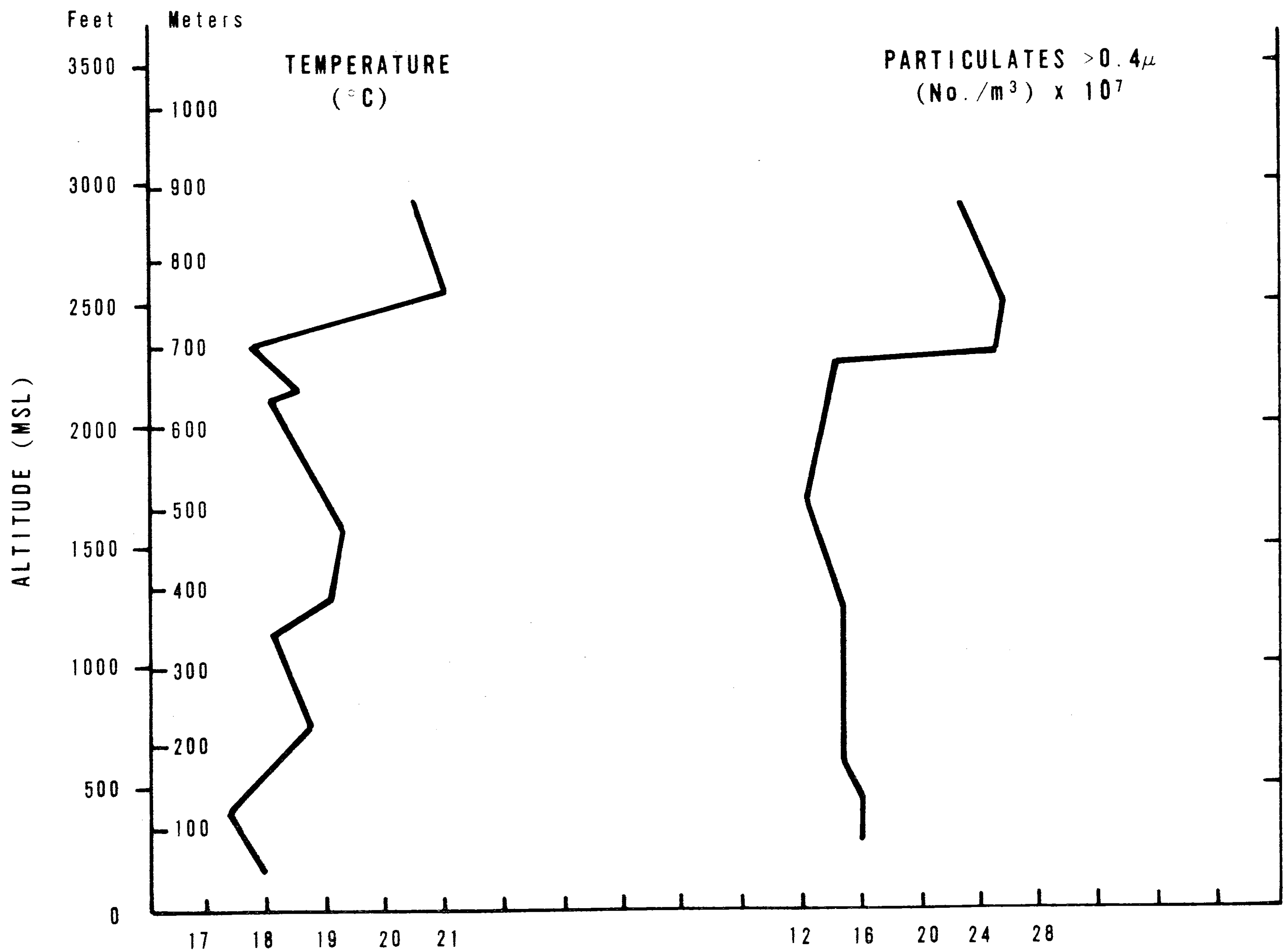
1540 - 10/27/72


Feet
Meters
TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
10
15
20
0
5
10

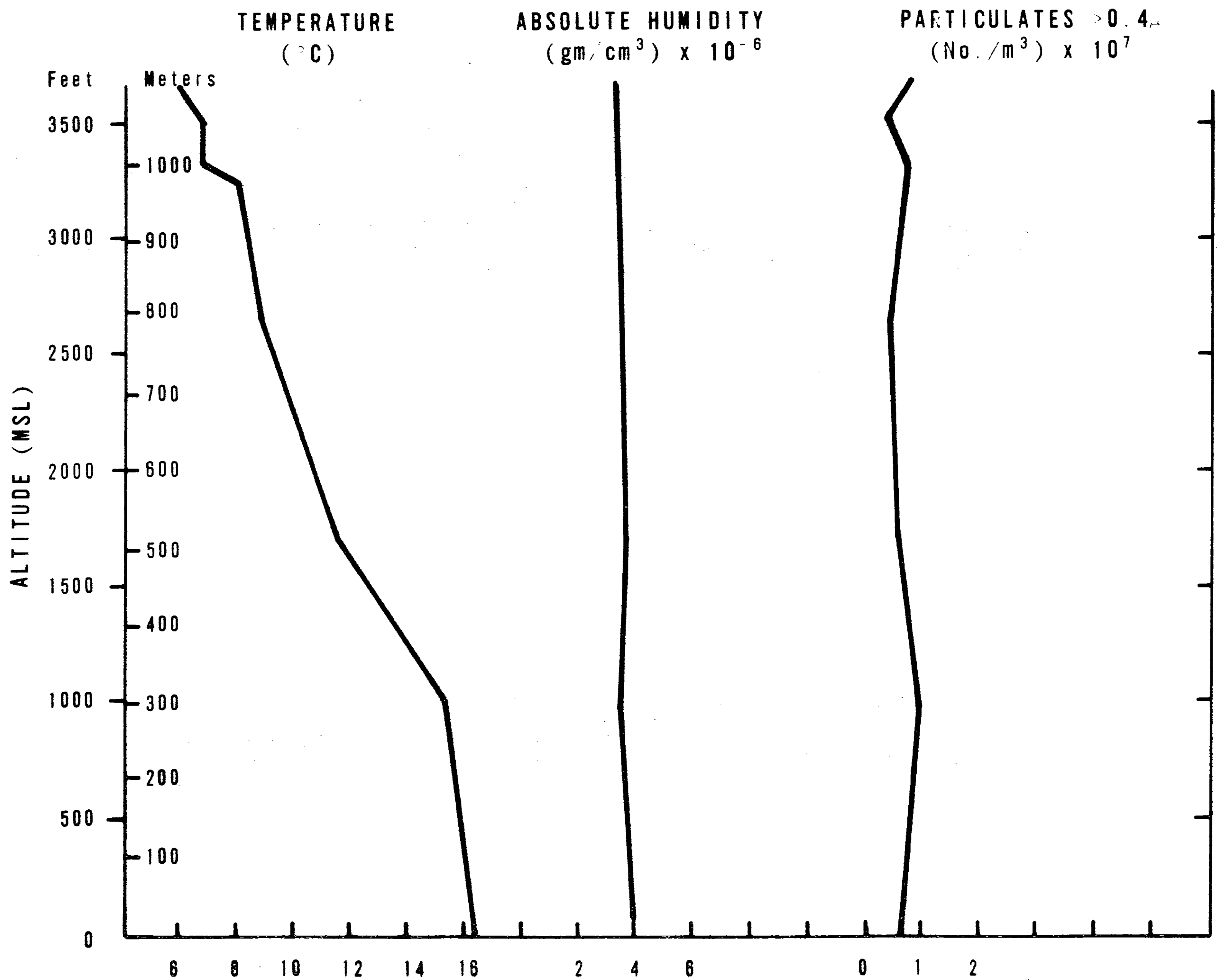
1435 - 11/1/72


Feet
Meters
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
TEMPERATURE
(°C)
16
17
18
19
20
21
PARTICULATES >0.4μ
(No./m³) x 10⁷
4
6
8
10
12
14
16

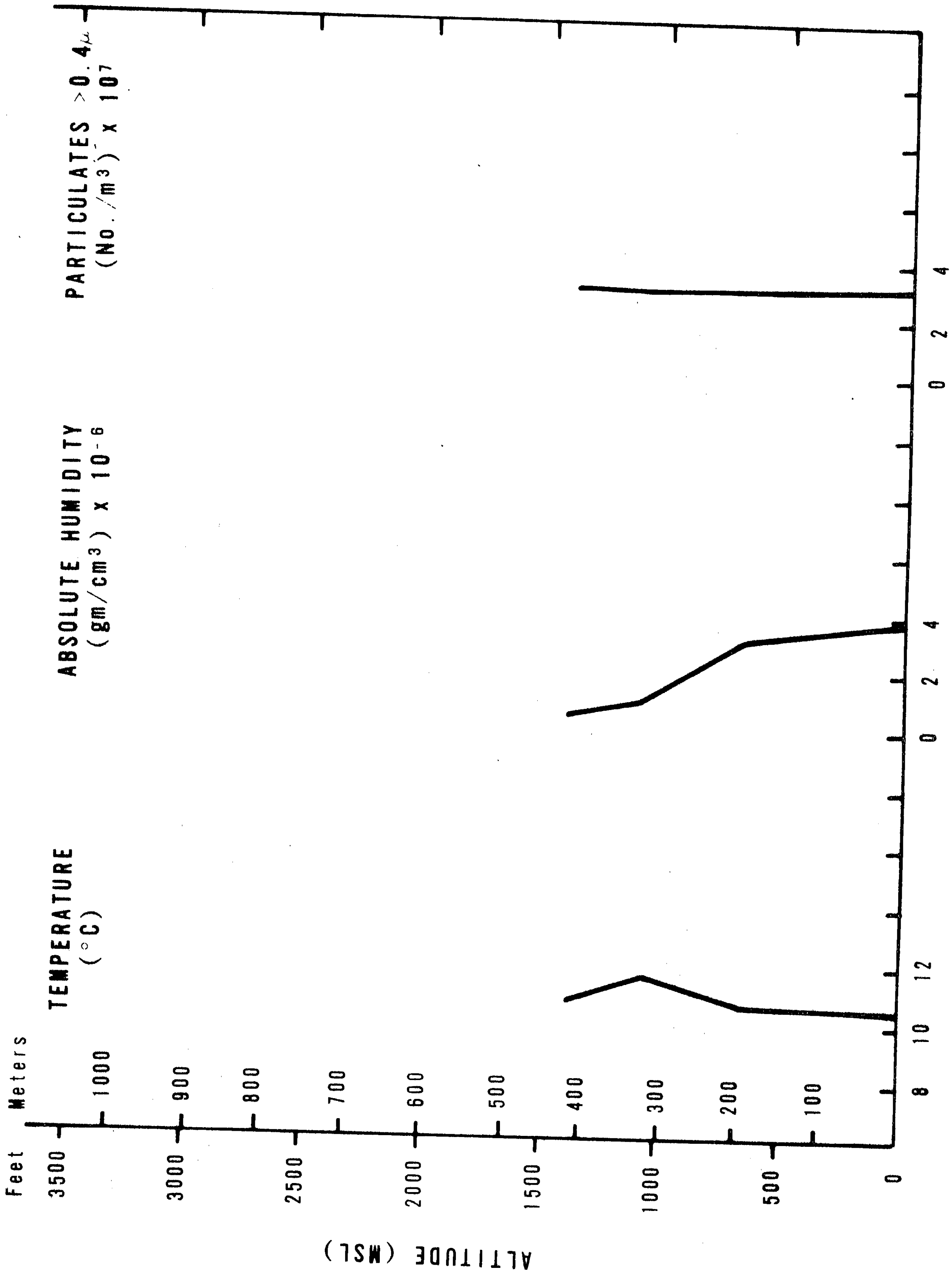
1420 - 11 27 72


Feet
Meters
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
ALTITUDE (MSL)
TEMPERATURE
(°C)
17
18
19
20
21
PARTICULATES >0.4μ
(No./m³) x 10⁷
12
16
20
24
28

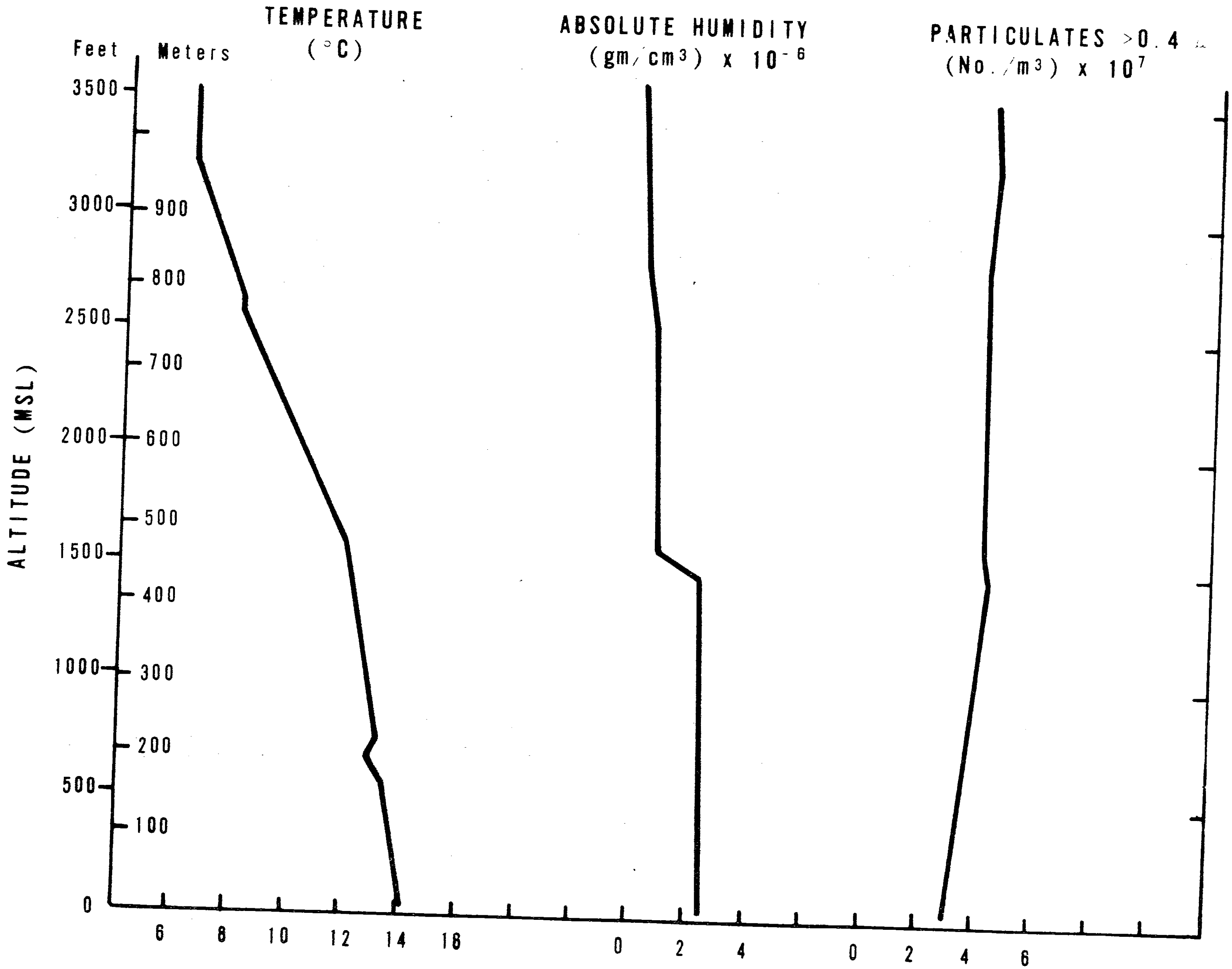
1500 - 11/27/72


TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
PARTICULATES >0.4μ
(No./m³) x 10⁷
Feet
Meters
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
6
8
10
12
14
16
2
4
6
0
1
2

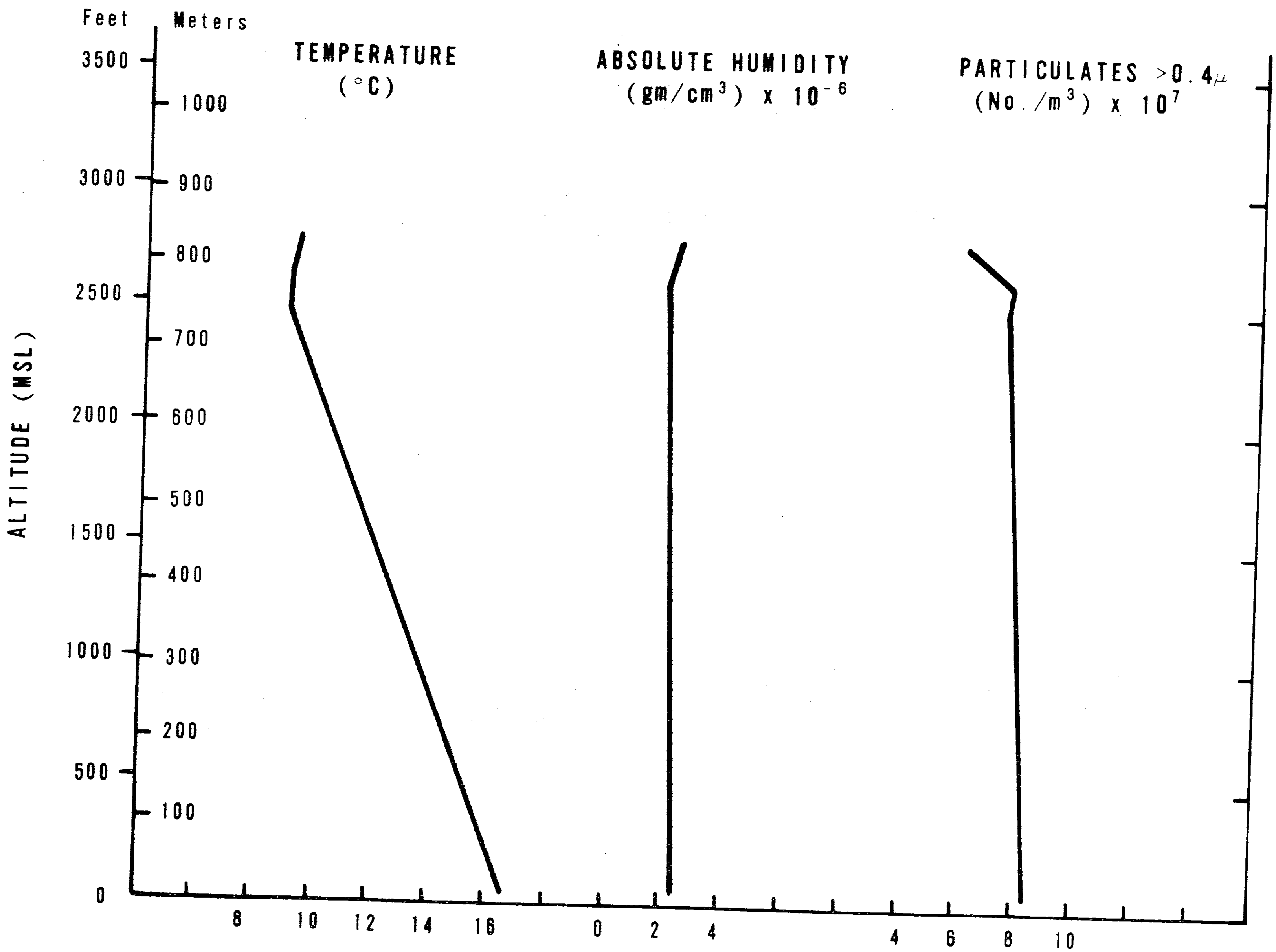
1435 - 3/27/73


PARTICULATES >0.4μ
(No./m³) x 10⁷
ABSOLUTE HUMIDITY
(gm/cm³) x 10-6
TEMPERATURE
(°C)
ALTITUDE (MSL)
Feet
3500
3000
2500
2000
1500
1000
500
0
Meters
1000
900
800
700
600
500
400
300
200
100
8
10
12
0
2
4
0
2
4

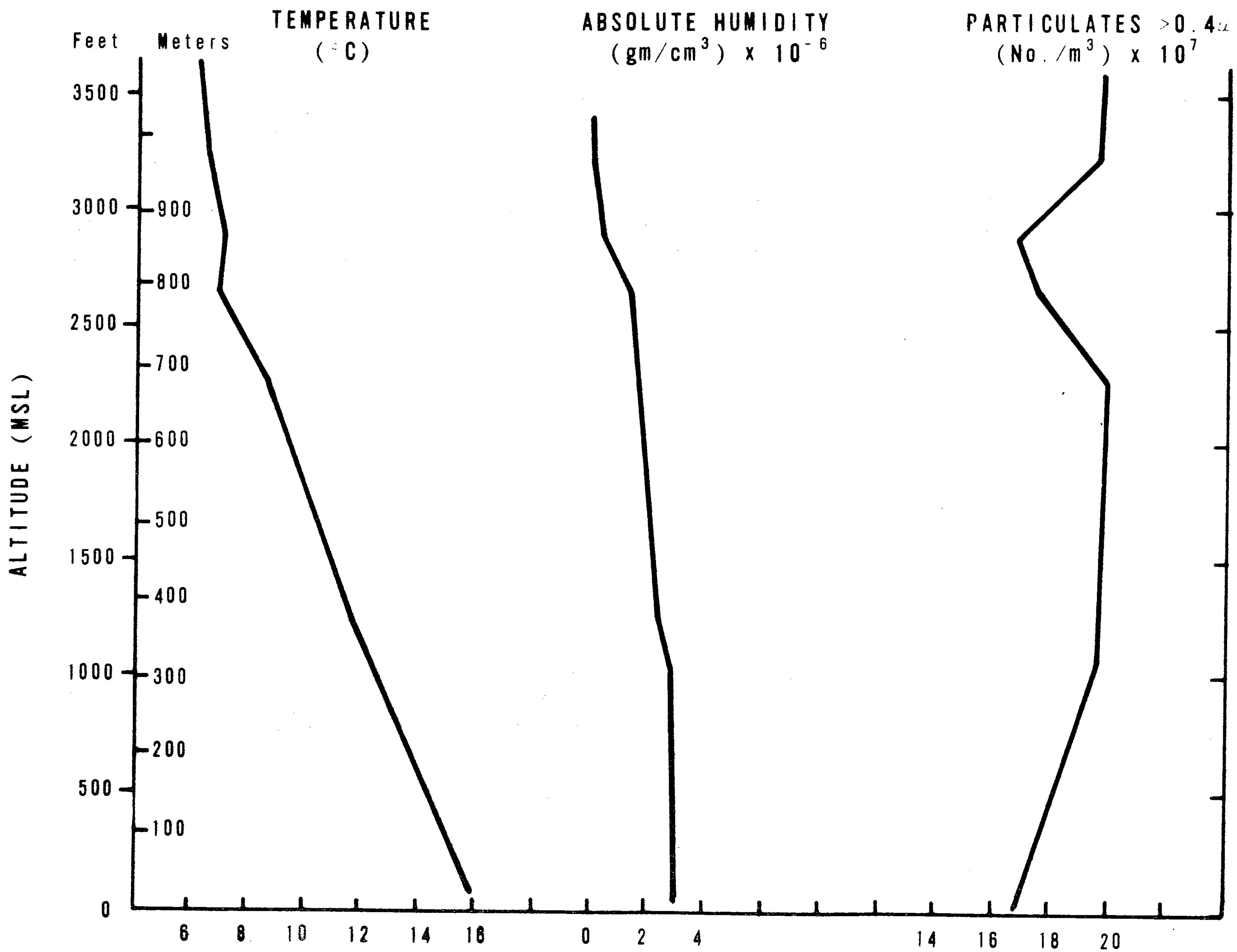
1055 - 3 29 73


TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm3) x 10-6
PARTICULATES >0.4
(No./m3) x 10^7
Feet
Meters
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
900
800
700
600
500
400
300
200
100
6
8
10
12
14
16
0
2
4
0
2
4
6

1235 - 3/29/73

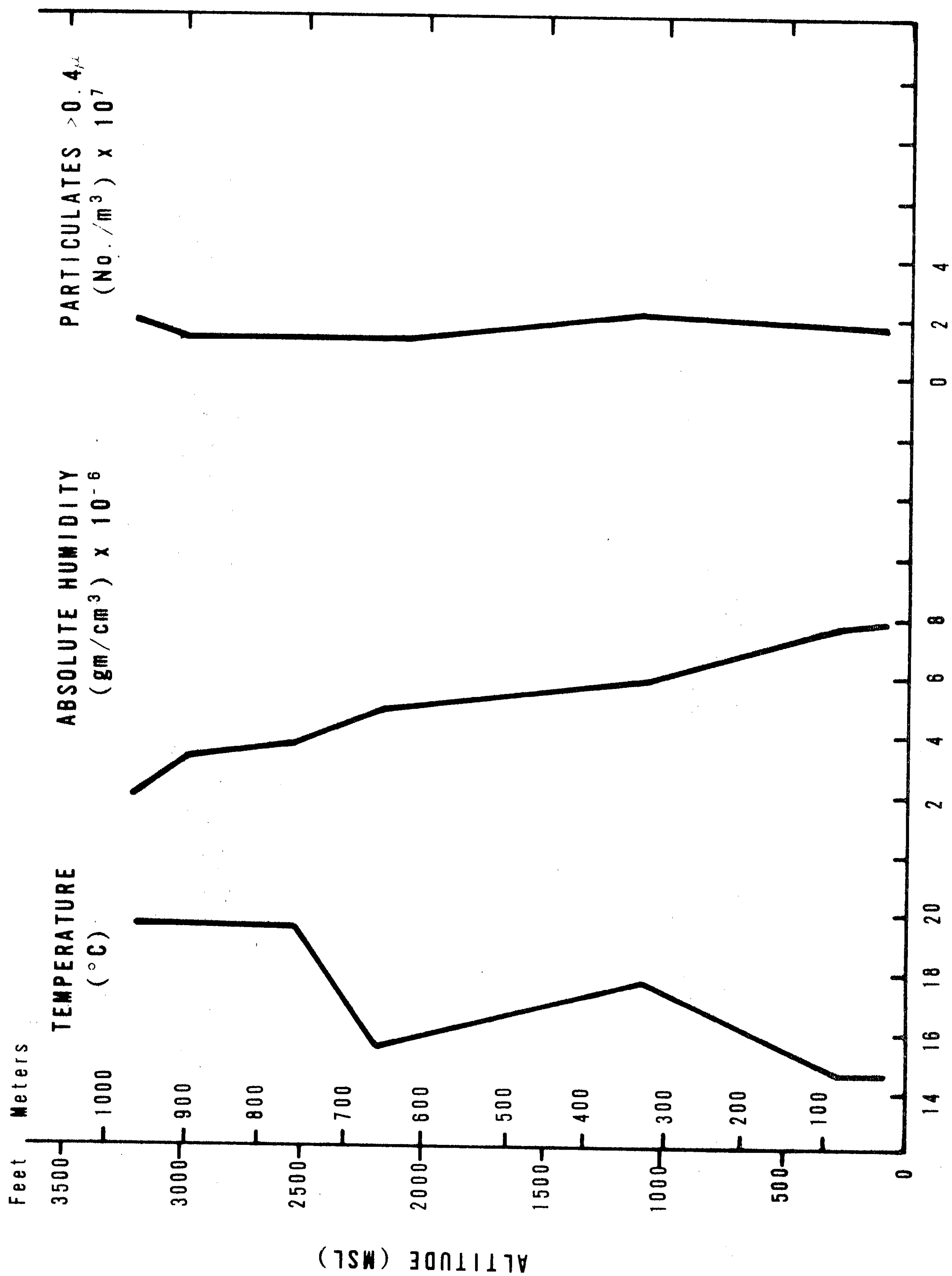

Feet
Meters
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
ALTITUDE (MSL)
TEMPERATURE
(°C)
8
10
12
14
16
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
0
2
4
PARTICULATES >0.4μ
(No./m³) x 10⁷
4
6
8
10

1512 - 3/29/73

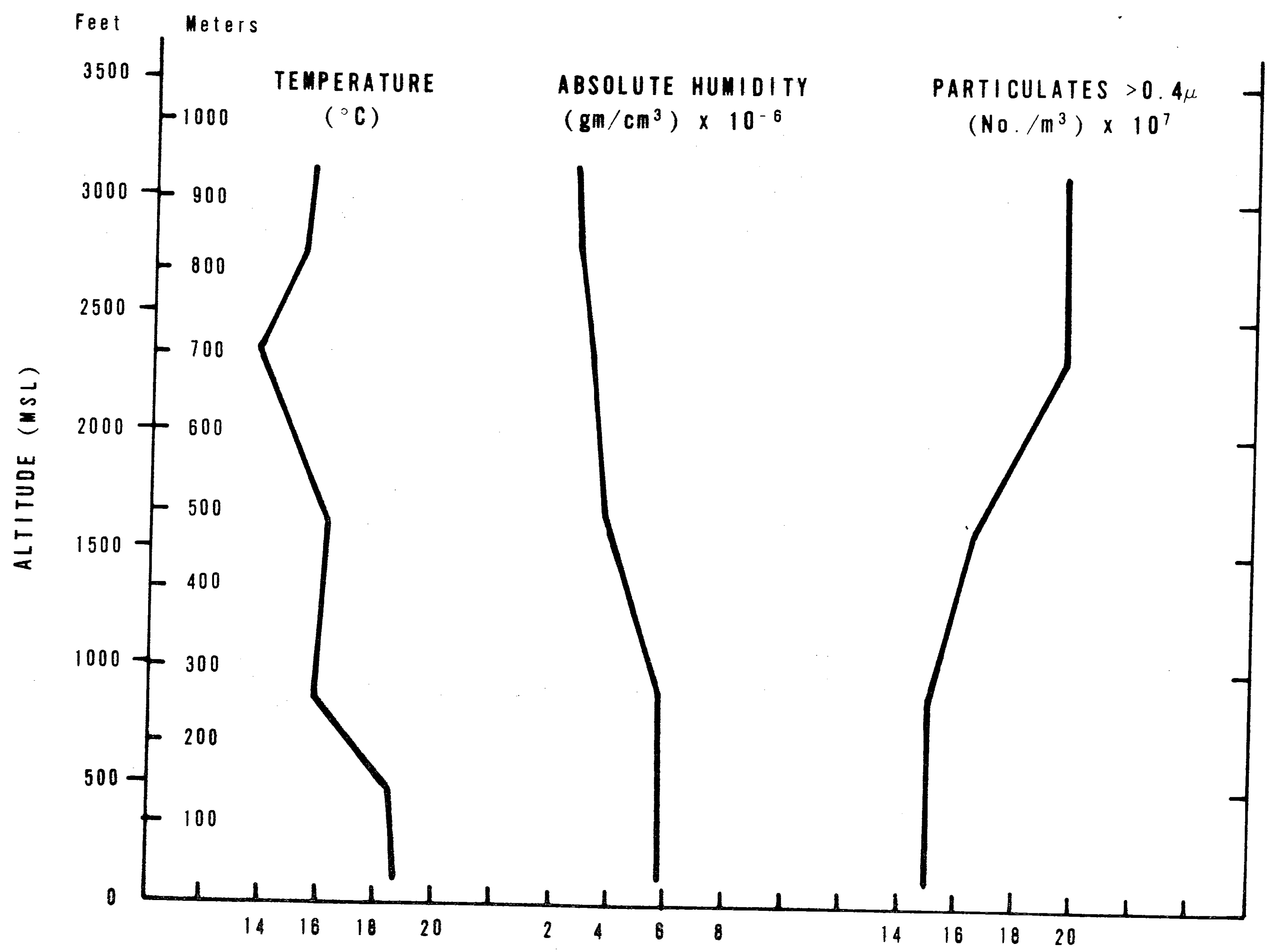


TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm3) x 10-6
PARTICULATES >0.4μ
(No./m3) x 107
ALTITUDE (MSL)
Feet
Meters
3500
3000
2500
2000
1500
1000
500
0
900
800
700
600
500
400
300
200
100
6
8
10
12
14
16
0
2
4
14
16
18
20

1540 - 3 20 73


PARTICULATES >0.4μ
(No./m³) x 10⁷
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
TEMPERATURE
(°C)
Feet
Meters
ALTITUDE (MSL)
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
14
16
18
20
2
4
6
8
0
2
4

0758 - 4/5/73


Feet
Meters
3500
3000
2500
2000
1500
1000
500
0
1000
900
800
700
600
500
400
300
200
100
ALTITUDE (MSL)
TEMPERATURE
(°C)
ABSOLUTE HUMIDITY
(gm/cm³) x 10⁻⁶
PARTICULATES >0.4μ
(No./m³) x 10⁷
14
16
18
20
2
4
6
8
14
16
18
20

1002 - 4/5/73

APPENDIX B

PARTICULATE DATA: Concentrations and Size Distributions

Twenty-five tables of particulate concentration and size distribution data are presented. The first table is in a different format since analysis techniques and size ranges examined differ from the rest of the analyses. All the data are for particles greater than 0.4 μ in diameter.

The standard format was designed to facilitate evaluation of the net fire contributions and size distributions from the plume penetration data. The heading includes the date and time of the sample, and the available information of the type of fire, type of fuel, fuel state, ambient meteorological conditions, and other relevant information. All data are in metric units.

The particulate concentrations are listed in the first column under the heading "total loading". To the right are six columns denoted by size intervals for which the size distribution of particles within a sample was determined.

Two types of observational data are presented: measured background concentrations and size distributions and measured total plume penetration concentrations and size distributions. The third type of data, - *i.e.* the net fire contributions - are obtained by subtracting the appropriate figure for the background from the corresponding total plume figure.

The particulate data are presented in three ways for each sample data type: percent of particles (by number), actual number concentration per cubic meter of air and, where possible, calculated estimates of the gravimetric concentrations within each size range. The units for the numbers in each line are given in the last column. The mass calculations require knowledge of particle densities which are obtained from a delineation of particle form as amorphous (i.e. liquid, S.G. $\simeq$ 0.8) or angular (crystalline, S.G. $\simeq$ 2.5).

Net fire size distributions are omitted in those cases in which the net fire contribution to the total concentration appears to be negative. For the causes of such questionable results, see text.

Finally, the time at which the sample was taken from which the size distribution for the background was determined is shown in parentheses following the words "BACKGROUND DATA". The background total concentration, however, is the average value measured before entering and after exiting the plume during the penetration runs. The tabulated data therefore contains the assumption that the background size distribution did not change between the time of the nearest sounding and the time of the plume penetrations.

Fire Plume Penetration Data

Number of Particulates > 0.4μ diam./m^3

Date 8/10/71

Type of data	Total concentration by number	Cumulative % less than stated size 1.0	3.0	10.0	μ diam.
Bkgnd	$1.61 \times 10^8/m^3$	42.0	99.0	99.8	
Backfire I	$4.35 \times 10^8/m^3$	55.0	91.	99.9	
Front Fire	$20.8 \times 10^8/m^3$	44.5	99.3	100.	
Backfire II	$4.88 \times 10^8/m^3$	36.4	99.	100.	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 11-5-71
FIELD PREP.
FUEL MOISTURE
PASS ELEVATIONS 70 700m
COMMENTS: Backgrounds

TIME 1500
FUEL TYPE
FLAME TEMPS.
INVERSION BASE(S)

TYPE Sounding
WIND SPEED 8-12 mps
COMBUSTION RATE

8 miles NE of Davis

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1500):								
	AMORPH. / ANG.	76.6	14.1	5.3	3.9	0.0	0.0	% of Total
12.0	AMORPH. / ANG.	9.2	1.7	0.64	0.47	0.0	0.0	$\#/m^3 x 10^6$
	AMORPH.							$\mu gm/m^3$
	ANG.							
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.							% of Total
	ANG.							
	AMORPH.							$\#/m^3 x 10^6$
	ANG.							
	AMORF.							$\mu gm/m^3$
	ANG.							
NET FIRE CONTRIBUTION:								
	AMORPH.							% of Total
	ANG.							
	AMORPH.							$\#/m^3 x 10^6$
	ANG.							
	AMORPH.							$\mu gm/m^3$
	ANG.							

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 11-5-71
FIELD PREP.
FUEL MOISTURE
PASS ELEVATIONS

TIME 1600
FUEL TYPE
FLAME TEMPS.
INVERSION BASE(S)

TYPE Sounding
WIND SPEED 8-12 mps
COMBUSTION RATE

COMMENTS: Backgrounds - 10 mi. North of Sacramento Metropolitan Airport

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1600):								
--	AMORPH. / ANG.	82.0	12.3	3.4	2.3	0.0	0.0	% of Total
25.0	AMORPH. / ANG.	20.5	3.1	0.85	0.58	0.0	0.0	$\#/m^3 x 10^6$
	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.							
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.							% of Total
	ANG.							
	AMORPH.							$\#/m^3 x 10^6$
	ANG.							
	AMORF.							$\mu gm/m^3$
	ANG.							
NET FIRE CONTRIBUTION:								
	AMORPH.							% of Total
	ANG.							
	AMORPH.							$\#/m^3 x 10^6$
	ANG.							
	AMORPH.							$\mu gm/m^3$
	ANG.							

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 11/1/72
FIELD PREP. Stacked straw
FUEL MOISTURE 11.2%
PASS ELEVATIONS 60 - 120 m
COMMENTS: Active plume

TIME 1410
FUEL TYPE Rice
FLAME TEMPS. 134° - 232°C
INVERSION BASE(S) 550 m

TYPE Pile burn
WIND SPEED 1 - 1.5 mps
COMBUSTION RATE ~17 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1435):								
	AMORPH.	83.4	12.7	1.5	0	0	0	% of Total
	ANG.	0	0	2.0	0.5	0	0	
7.14	AMORPH.	5.95	0.91	0.11	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0	0.14	0.04	0	0	
4.25	AMORPH.	0.24	0.31	0.29	0	0	0	$\mu gm/m^3$
	ANG.	0	0	1.13	2.28	0	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	52.7	34.5	4.7	0	0	0	% of Total
	ANG.	0	0	4.1	4.1	0	0	
11.11	AMORPH.	5.87	3.84	0.52	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0	0.43	0.46	0	0	
35.53	AMORF.	0.24	1.32	1.43	0	0	0	$\mu gm/m^3$
	ANG.	0	0	3.61	28.93	0	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	-2.56	73.8	10.5	0	0	0	% of Total
	ANG.	0	0	7.9	10.6	0	0	
4.0	AMORPH.	-0.08	2.93	0.41	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0	0.31	0.42	0	0	
31.3	AMORPH.	0	1.01	1.14	0	0	0	$\mu gm/m^3$
	ANG.	0	0	2.48	26.6	0	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 4/5/73
FIELD PREP. Wind rows
FUEL MOISTURE 1470
PASS ELEVATIONS 60 m
COMMENTS:

TIME 1010
FUEL TYPE Rice
FLAME TEMPS. 275° to 733°
INVERSION BASE(S) a) 244m
b) 700m

TYPE Front
WIND SPEED 4.0 mps
COMBUSTION RATE 19.4 kg min.

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1000):								
	AMORPH.	50.1	16.5	1.3	0	0	0	% of Total
	ANG.	17.2	8.5	3.3	2.1	0.5	0	
147	AMORPH.	74.1	24.4	1.92	0	0	0	$\#/m^3 x10^6$
	ANG.	25.5	12.6	4.88	3.11	0.74	0	
635	AMORPH.	2.95	0.97	5.27	0	0	0	$\mu gm/m^3$
	ANG.	2.94	12.5	38.7	197	375	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	57.6	6.6	0.5	0	0	0	% of Total
	ANG.	19.0	12.7	1.6	1.4	0.6	0	
175	AMORPH.	100.8	11.6	0.875	0	0	0	$\#/m^3 x10^6$
	ANG.	33.2	22.2	2.80	2.45	1.05	0	
749	AMORF.	4.01	-3.42	2.41	0	0	0	$\mu gm/m^3$
	ANG.	3.83	22.0	33.0	155	532	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	96.3	-46.2	-3.8	0	0	0	% of Total
	ANG.	27.8	34.6	-7.5	-2.4	1.1	0	
27.73	AMORPH.	26.7	-12.8	-1.04	0	0	0	$\#/m^3 x10^6$
	ANG.	7.70	9.60	-2.08	-0.66	0.31	0	
113	AMORPH.	1.06	-4.39	-2.86	0	0	0	$\mu gm/m^3$
	ANG.	0.89	9.52	-5.72	-41.9	157	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 4/5/73
FIELD PREP. Wind rowed
FUEL MOISTURE 11%
PASS ELEVATIONS 60m
COMMENTS:

TIME 0840
FUEL TYPE Rice
FLAME TEMPS. NA
INVERSION BASE(S) a) 120m
b) 670m

TYPE Backfire
WIND SPEED 3 mps
COMBUSTION RATE 7.9 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (0800):								
	AMORPH.	34	22.5	1.8	0	0	0	% of Total
	ANG.	20.7	14.4	3.5	1.1	2.1	0	
139.54	AMORPH.	40.8	27.0	21.6	0	0	0	$\#/m^3 x10^6$
	ANG.	24.8	17.3	4.20	1.32	2.52	0	
1432	AMORPH.	1.63	9.27	5.93	0	0	0	$\mu gm/m^3$
	ANG.	2.86	17.2	33.3	83.8	1,280.	0	
TOTAL PENETRATION PLUME LOADING:								
99.9	AMORPH.	65.2	10.9	0.6	0	0	0	% of Total
	ANG.	10.6	6.8	3.2	1.8	0.8	0	
151.	AMORPH.	99.1	16.6	0.912	0	0	0	$\#/m^3 x10^6$
	ANG.	16.1	10.3	4.86	2.74	1.22	0	
843	AMORF.	3.95	5.70	2.50	0	0	0	$\mu gm/m^3$
	ANG.	1.86	10.3	38.1	174	620	0	
NET FIRE CONTRIBUTION:								
100.1	AMORPH.	185.8	-33.9	-3.9	0	0	0	% of Total
	ANG.	-28	-22.3	2.0	4.6	-4.2	0	
31.7	AMORPH.	58.3	-10.4	-1.25	0	0	0	$\#/m^3 x10^6$
	ANG.	-8.70	-7.00	0.66	1.42	-1.30	0	
(-589)	AMORPH.							$\mu gm/m^3$
	ANG.							

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/29/73 TIME 1640 TYPE Front
FIELD PREP. Spread straw FUEL TYPE Rice WIND SPEED 2.2 mph
FUEL MOISTURE 11% FLAME TEMPS. NA COMBUSTION RATE 139 kg min^{-1}
PASS ELEVATIONS 305-335m INVERSION BASE(S) 790m
COMMENTS: Spread plume

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1515):								
	AMORPH.	31.7	7.7	1.5	0	0	0	% of Total
	ANG.	35.5	7.7	12.1	1.5	2.4	0	
	AMORPH.	57.1	13.9	2.70	0	0	0	$\#/m^3 x10^6$
180	ANG.	63.9	13.9	21.8	2.70	4.32	0	
	AMORPH.	2.28	4.77	7.42	0	0	0	$\mu gm/m^3$
2,570	ANG.	7.36	13.8	173.	171.	2.19	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	57.4	5.11	0.5	0	0	0	% of Total
	ANG.	22.8	8.42	3.0	2.1	0.5	0.2	
	AMORPH.	140	12.5	1.22	0	0	0	$\#/m^3 x10^6$
244	ANG.	55.6	20.5	7.32	5.12	1.22	0.49	
	AMORF.	5.58	4.29	3.35	0	0	0	$\mu gm/m^3$
3,026	ANG.	8.32	20.3	58	324	619	1.98	
NET FIRE CONTRIBUTION:								
	AMORPH.	103.	-1.7	-1.8	0	0	0	% of Total
	ANG.	+10.3	8.2	18.1	3.0	-3.9	0.6	
	AMORPH.	82.9	-1.40	-1.48	0	0	0	$\#/m^3 x10^6$
80.2	ANG.	8.30	6.60	-14.5	2.42	-3.10	0.49	
	AMORPH.	3.30	-0.48	-11.07	0	0	0	$\mu gm/m^3$
455	ANG.	0.96	6.54	-115	153	-1.57	1.98	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/29/73
FIELD PREP. Spread straw
FUEL MOISTURE 11%
PASS ELEVATIONS 60-120m
COMMENTS: Active plume

TIME 1620
FUEL TYPE Rice
FLAME TEMPS. NA
INVERSION BASE(S) 790m
(weak stable layer 300m)

TYPE Front
WIND SPEED 212 mps
COMBUSTION RATE 139 kg/min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1515):								
	AMORPH.	31.7	7.7	1.5	0	0	0	% of Total
	ANG.	35.5	7.7	12.1	1.5	2.4	0	
93.8	AMORPH.	29.7	7.2	1.41	0	0	0	$\#/m^3 x10^6$
	ANG.	33.3	7.2	11.3	1.4	2.2	0	
1279	AMORPH.	1.2	2.5	3.9	0	0	0	$\mu gm/m^3$
	ANG.	3.8	7.2	31.0	89.	1.1	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	54.3	22.5	0.5	0	0	0	% of Total
	ANG.	7.5	9.0	4.2	1.5	0.4	0.2	
166.8	AMORPH.	90.5	37.5	0.8	0	0	0	$\#/m^3 x10^6$
	ANG.	12.5	15.0	7.0	2.5	0.7	0.3	
1883	AMORF.	3.6	12.9	2.3	0	0	0	$\mu gm/m^3$
	ANG.	1.4	14.9	3.1	159.	340	1353	
NET FIRE CONTRIBUTION:								
	AMORPH.	82.8	41.3	-0.8	0	0	0	% of Total
	ANG.	-28.4	10.6	-5.9	1.5	-2.1	0.4	
73.1	AMORPH.	60.8	30.3	-0.6	0	0	0	$\#/m^3 x10^6$
	ANG.	-20.8	7.8	-4.3	1.1	-1.6	.3	
604	AMORPH.	-2.4	10.4	-1.6	0	0	0	$\mu gm/m^3$
	ANG.	-2.4	7.7	-34.1	69.8	-801	1353	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/29/73
FIELD PREP. Spread straw
FUEL MOISTURE 11%
PASS ELEVATIONS 60-150m
COMMENTS:

TIME 1520
FUEL TYPE Rice
FLAME TEMPS. NA
INVERSION BASE(S) 790m
(weak stable layer 2300m)

TYPE Back fire
WIND SPEED 3.5 mps
COMBUSTION RATE 10.7 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1515):								
	AMORPH.	31.7	7.7	1.5	0	0	0	% of Total
	ANG.	35.5	7.7	12.1	1.5	2.4	0	
48.0	AMORPH.	15.2	3.70	0.72	0	0	0	$\#/m^3 x10^6$
	ANG.	17.0	3.70	5.81	0.72	1.15	0	
684.63	AMORPH.	0.60	1.27	1.978	0	0	0	$\mu gm/m^3$
	ANG.	1.96	3.67	46.1	45.7	583	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	70	14	0.3	0.3	0	0	% of Total
	ANG.	5.3	5.1	3.4	1.2	0.3	0.1	
95.46	AMORPH.	66.8	13.4	0.28	0.28	0	0	$\#/m^3 x10^6$
	ANG.	5.06	4.87	3.24	1.14	0.28	0.09	
646.98	AMORF.	2.67	4.60	0.79	6.28	0	0	$\mu gm/m^3$
	ANG.	0.59	4.83	25.7	72.3	143.	386.	
NET FIRE CONTRIBUTION:								
	AMORPH.	109	20.5	-0.9	0.6	0	0	% of Total
	ANG.	-25.5	2.5	-5.5	0.9	-1.9	0.2	
47.50	AMORPH.	51.6	9.70	-0.43	0.28	0	0	$\#/m^3 x10^6$
	ANG.	-11.9	1.17	-2.57	0.42	-0.86	0.09	
(-35.68)	AMORPH.							$\mu gm/m^3$
	ANG.							

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/29/73
TIME 1230
TYPE Front
FIELD PREP. Spread straw
FUEL TYPE Rice
WIND SPEED 4.5 mps
FUEL MOISTURE 11%
FLAME TEMPS. Na
COMBUSTION RATE 29.2 kg min^{-1}
PASS ELEVATIONS 215 m
INVERSION BASE(S) Isothermal layer @ 215 m
COMMENTS: Smoldering plume

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1235):								
	AMORPH.	50.5	12.1	2.2	0	0	0	% of Total
	ANG.	21.7	6.7	5.0	0.6	1.1	0	
282.	AMORPH.	143.	34.2	6.23	0	0	0	$\#/m^3 x 10^6$
	ANG.	61.4	19.0	14.2	1.70	3.11	0	
1858.	AMORPH.	5.71	11.7	17.1	0	0	0	$\mu gm/m^3$
	ANG.	7.1	18.8	113.	107.	1577.	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	43.0	7.0	1.1	0	0.4	0	% of Total
	ANG.	17.1	22.4	5.2	0	3.5	0.4	
546.	AMORPH.	235.	38.2	6.01	0	2.18	0	$\#/m^3 x 10^6$
	ANG.	93.4	122	28.4	0	19.1	2.18	
18,977	AMORF.	9.48	13.1	16.51	0	0	0	$\mu gm/m^3$
	ANG.	10.8	121.	225.	31.7	9693.	8855.	
NET FIRE CONTRIBUTION:								
	AMORPH.	35.0	1.5	-0.2	0	0.7	0	% of Total
	ANG.	12.2	39.1	5.5	-0.7	6.1	0.7	
263	AMORPH.	92.0	4.0	-0.22	0	2.2	0	$\#/m^3 x 10^6$
	ANG.	32.0	103.	14.2	-1.70	16.0	2.18	
17,500	AMORPH.	3.6	1.37	-0.60	0	382.	0	$\mu gm/m^3$
	ANG.	3.7	102.	112.	-76.	8115.	8855.	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/29/73
FIELD PREP. Spread straw
FUEL MOISTURE 11%
PASS ELEVATIONS 60 - 150 m
COMMENTS: Active front plume

TIME 12:10
FUEL TYPE Rice
FLAME TEMPS. -
INVERSION BASE(S) 412 m

TYPE Front
WIND SPEED 4-5 mps
COMBUSTION RATE 29.2 kg min⁻

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1235):								
--	AMORPH.	0.5	12.1	2.2	0	0	0	% of Total
	ANG.	21.7	6.7	5.0	0.6	1.1	0	
303.	AMORPH.	153.	36.7	6.7	0	0	0	$\#/m^3 x10^6$
	ANG.	65.8	20.3	15.2	1.8	3.3	0	
1990.	AMORPH.	6.11	12.6	18.3	0	0	0	$\mu gm/m^3$
	ANG.	7.59	20.1	120.	115.	1689.	0	
TOTAL PENETRATION PLUME LOADING:								
--	AMORPH.	55.1	10.4	0.3	0	0	0	% of Total
	ANG.	26.3	6.6	1.2	0	0.1	0	
334.	AMORPH.	184.	34.7	1.0	0	0	0	$\#/m^3 x10^6$
	ANG.	87.8	22.0	4.0	0	0.3	0	
253.	AMORF.	7.35	11.9	2.7	0	0	0	$\mu gm/m^3$
	ANG.	10.1	21.8	31.6	0	167.	0	
NET FIRE CONTRIBUTION:								
--	AMORPH.	117.	-13	-26.3	0	0	0	% of Total
	ANG.	91	-6.5	-51.9	-9.4	-13.6	0	
31.	AMORPH.	31.0	-2.0	-5.7	0	0	0	$\#/m^3 x10^6$
	ANG.	22.0	1.7	-11.2	-1.82	-3.0	0	
(-1737)	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.	--	--	--	--	--	--	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/29/73
FIELD PREP. Spread straw
FUEL MOISTURE 14%
PASS ELEVATIONS 60 - 150 m
COMMENTS:

TIME 1110
FUEL TYPE Rice
FLAME TEMPS. -
INVERSION BASE(S) 200 m

TYPE Backfire
WIND SPEED 4 mps
COMBUSTION RATE 13.3 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1100):								
	AMORPH.	35.8	18.1	1.3	0	0	0	% of Total
	ANG.	10.2	17.2	11.1	4.9	1.1	0.3	
54.1	AMORPH.	19.4	9.79	0.703	0	0	0	$\#/m^3 x10^6$
	ANG.	5.52	9.31	6.01	2.65	0.59	0.16	
1191.	AMORPH.	0.77	3.36	1.93	0	0	0	$\mu gm/m^3$
	ANG.	0.64	9.23	47.7	168.	301.	658.	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	65.8	12.2	1.8	0.4	0.1	0	% of Total
	ANG.	13.0	4.3	1.8	0.4	0.4	0	
65.3	AMORPH.	42.9	7.95	1.17	0.26	0.06	0	$\#/m^3 x10^6$
	ANG.	8.48	2.80	1.17	0.26	0.26	0	
186.	AMORF.	1.71	2.73	3.21	5.73	11.4	0	$\mu gm/m^3$
	ANG.	0.98	2.78	9.28	16.5	132.	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	210.	-16.4	+4.2	2.3	0.6	0	% of Total
	ANG.	26.5	-58.2	-43.1	-21.4	-3.0	-0.1	
11.2	AMORPH.	23.5	-1.84	0.46	0.26	0.06	0	$\#/m^3 x10^6$
	ANG.	2.96	-6.51	-4.84	-2.39	-0.33	-0.16	
(-1005.)	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.	--	--	--	--	--	--	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/27/73 TIME 1525 TYPE Front
FIELD PREP. Spread straw FUEL TYPE Rice WIND SPEED 2.5 to 4 mps
FUEL MOISTURE 12.0% FLAME TEMPS. - COMBUSTION RATE 19 kg min^{-1}
PASS ELEVATIONS - INVERSION BASE(S) Isothermal layer 975 m
COMMENTS: Wind N 8-10 mps all morning

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1435):								
	AMORPH.	40.1	19.2	0.9	0	0	0	% of Total
	ANG.	16.9	16.0	4.5	1.7	0.3	0.3	
146.	AMORPH.	58.9	28.2	1.32	0	0	0	$\#/m^3 x10^6$
	ANG.	24.8	23.5	6.62	250.	0.44	0.44	
2268.	AMORPH.	2.35	9.68	3.63	0	0	0	$\mu gm/m^3$
	ANG.	2.86	23.3	52.5	158.	224.	1791.	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	58.7	20.8	0.3	0	0	0	% of Total
	ANG.	7.7	9.9	1.4	1.0	0.1	0.1	
148.	AMORPH.	87.3	31.0	0.30	0	0	0	$\#/m^3 x10^6$
	ANG.	11.3	14.8	2.09	1.49	0.15	0.15	
822.	AMORF.	3.48	10.6	0.83	0	0	0	$\mu gm/m^3$
	ANG.	1.30	14.6	16.5	94.5	75.5	605.	
NET FIRE CONTRIBUTION:								
	AMORPH.	1500.	144.	-53.5	0	0	0	% of Total
	ANG.	-704	-458	-235	-52.6	-15.2	-15.2	
1.85	AMORPH.	28.4	2.80	-1.02	0	0	0	$\#/m^3 x10^6$
	ANG.	-13.5	-8.70	-4.53	-1.01	-0.29	-0.29	
(-1445.)	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.	--	--	--	--	--	--	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 3/27/73 TIME 1447 TYPE Backfire
FIELD PREP. Spread straw FUEL TYPE Rice straw WIND SPEED 2.5 - 4 mps from NE
FUEL MOISTURE 14.2% FLAME TEMPS. 134° - 484°C COMBUSTION RATE 5.8 kg min^{-1}
PASS ELEVATIONS 90 - 180 m INVERSION BASE(S) Isothermal layer at 975 m
COMMENTS: Morning, strong north wind until about 1 pm

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1435):								
	AMORPH.	40.1	19.2	0.9	0	0	0	% of Total
	ANG.	16.9	16.0	4.5	1.7	0.3	0.3	
11.5	AMORPH.	4.61	2.21	0.10	0	0	0	$\#/m^3 x10^6$
	ANG.	1.94	1.84	0.52	0.20	0.03	0.03	
175.2	AMORPH.	0.18	0.76	0.29	0	0	0	$\mu gm/m^3$
	ANG.	0.22	1.82	4.11	12.4	17.2	138.	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	397	29.8	0.9	0	0	0	% of Total
	ANG.	3.6	22.0	3.0	0.2	0.3	0.6	
51.0	AMORPH.	20.2	15.2	0.45	0	0	0	$\#/m^3 x10^6$
	ANG.	1.83	11.2	1.53	0.10	0.15	0.30	
1354.	AMORF.	0.80	5.22	1.26	0	0	0	$\mu gm/m^3$
	ANG.	0.23	11.10	12.1	6.48	77.6	1239.	
NET FIRE CONTRIBUTION:								
	AMORPH.	39.8	33.0	0.9	0	0	0	% of Total
	ANG.	-0.3	23.8	2.6	-0.2	0.3	0	
39.7	AMORPH.	15.6	13.0	0.35	0	0	0	$\#/m^3 x10^6$
	ANG.	0.11	9.36	1.01	-0.09	0.12	0.27	
1178.	AMORPH.	0.62	4.46	0.97	0	0	0	$\mu gm/m^3$
	ANG.	0.01	9.28	8.01	-5.96	60.4	1100.89	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 11/27/72
FIELD PREP. Spread
FUEL MOISTURE -
PASS ELEVATIONS 330 m
COMMENTS: Following spread plume for 7 minutes

TIME 1440
FUEL TYPE -
FLAME TEMPS. -
INVERSION BASE(S) 330 m

TYPE Front
WIND SPEED ?
COMBUSTION RATE -

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1430):								
--	AMORPH.	63.6	23.1	2.6	0	0	0	% of Total
	ANG.	0	1.3	2.6	5.3	1.3	0	
6.02	AMORPH.	3.8	1.4	.15	0	0	0	$\#/m^3 x10^6$
	ANG.	0	.07	.15	.31	.07	0	
221.9	AMORPH.	1.99	3.00	3.08	0	0	0	$\mu gm/m^3$
	ANG.	0	.15	3.08	60.6	150.	0	
TOTAL PENETRATION PLUME LOADING:								
--	AMORPH.	72.2	20.5	1.5	0	0	0	% of Total
	ANG.	0	0.5	2.0	2.3	0.5	0	
6.82	AMORPH.	4.9	1.4	.10	0	0	0	$\#/m^3 x10^6$
	ANG.	0	.03	.13	.15	.03	0	
112.6	AMORF.	2.56	3.00	2.10	0	0	0	$\mu gm/m^3$
	ANG.	0	.07	2.67	29.3	72.9	0	
NET FIRE CONTRIBUTION:								
--	AMORPH.	137.	0	-6.1	0	0	0	% of Total
	ANG.	0	-5.0	-2.4	-19	-4.	0	
0.8	AMORPH.	1.1	0	- .05	0	0	0	$\#/m^3 x10^6$
	ANG.	0	- .04	- .06	- .16	- .04	0	
(-111)	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.	--	--	--	--	--	--	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 10/27/72 TIME 1515 TYPE Pile
FIELD PREP. Stack spread straw FUEL TYPE Rice? WIND SPEED 1 mps
FUEL MOISTURE 19.2% FLAME TEMPS. - COMBUSTION RATE 17 kg min^{-1}
PASS ELEVATIONS -- INVERSION BASE(S) --
COMMENTS: Smoldering

TOTAL LOADING	PHYSICAL APPEARENCE	0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1530):								
	AMORPH.	77.8	11.6	2.7	0	0	0	% of Total
	ANG.	0	0.9	3.1	3.6	0.4	0	
1.82	AMORPH.	1.13	0.17	0.40	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0.01	0.04	0.05	0.01	0	
7.91	AMORPH.	0.04	0.06	1.10	0	0	0	$\mu gm/m^3$
	ANG.	0	0.01	0.36	3.30	3.04	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	63.4	26.1	2.1	0	0	0	% of Total
	ANG.	0	0.7	4.2	2.8	0.7	0	
50.5	AMORPH.	32.0	13.2	1.06	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0.35	2.12	1.41	0.35	0	
297.	AMORF.	1.27	4.52	2.91	0	0	0	$\mu gm/m^3$
	ANG.	0	0.35	16.9	92.8	179.	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	62.8	26.7	2.1	0	0	0	% of Total
	ANG.	0	0.7	4.2	2.8	0.7	0	
48.7	AMORPH.	30.9	13.0	0.660	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0.34	2.08	1.41	0.35	0	
289.	AMORPH.	1.23	4.46	1.81	0	0	0	$\mu gm/m^3$
	ANG.	0	0.34	16.5	89.4	176.	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 10/27/72 | TIME 1500 | TYPE Pile burn
FIELD PREP. Piled straw | FUEL TYPE Rice | WIND SPEED ~ 1 mps
FUEL MOISTURE 19.2% | FLAME TEMPS. 670-1280°C | COMBUSTION RATE 17 kg min^{-1}
PASS ELEVATIONS 90-180 m | INVERSION BASE(S) weak stable layer @ 150 m
COMMENTS: Active flame

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1530):								
	AMORPH.	77.8	11.6	2.7	0	0	0	% of Total
	ANG.	0	0.9	3.1	3.6	0.4	0	
2.04	AMORPH.	1.58	0.24	0.05	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0.02	0.06	0.07	0.01	0	
9.50	AMORPH.	0.06	0.08	0.15	0	0	0	$\mu gm/m^3$
	ANG.	0	0.02	0.50	4.63	4.06	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	91.0	7.8	0.3	0	0	0	% of Total
	ANG.	0	0	0.3	0	0.8	0	
257.	AMORPH.	234.	20.0	0.77	0	0	0	$\#/m^3 x10^6$
	ANG.	0	0	0.77	0	2.06	0	
1073.	AMORF.	9.33	6.95	2.13	0	0	0	$\mu gm/m^3$
	ANG.	0	0	6.13	0.19	1049.0	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	91.0	7.6	0.18	0	0	0	% of Total
	ANG.	0	-0.05	0.16	0.19	0.82	0	
255.	AMORPH.	232.	20.0	0.72	0	0	0	$\#/m^3 x10^6$
	ANG.	0	-0.02	0.71	-0.07	2.06	0	
1064.	AMORPH.	9.27	6.87	1.98	0	0	0	$\mu gm/m^3$
	ANG.	0	-0.02	5.63	-4.44	1044.	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 10/25/72
FIELD PREP. Spread study
FUEL MOISTURE 19%
PASS ELEVATIONS 60-120 m
COMMENTS:

TIME 1605
FUEL TYPE Rice
FLAME TEMPS. 555°C
INVERSION BASE(S) 850 m

TYPE Back fire
WIND SPEED --
COMBUSTION RATE 16.0 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1400):								
	AMORPH.	85.9	9.6	0.7	0	0	0	% of Total
	ANG.	0.2	1.4	0.2	0.7	1.0	0	
70.21	AMORPH.	60.5	6.76	0.49	0	0	0	$\#/m^3 x10^6$
	ANG.	0.14	0.99	0.14	0.49	0.70	0	
394.	AMORPH.	2.42	2.32	1.35	0	0	0	$\mu gm/m^3$
	ANG.	0.02	0.98	1.11	31.	355.	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	83.2	8.8	3.5	0.9	0	0	% of Total
	ANG.	0	0	0.9	1.8	0.9	0	
81.0	AMORPH.	67.3	7.12	2.83	0.73	0	0	$\#/m^3 x10^6$
	ANG.	0	0	0.73	1.46	0.83	0	
548.	AMORF.	2.69	2.44	7.78	16.0	0	0	$\mu gm/m^3$
	ANG.	0	0	5.79	92.	421.	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	63.0	3.3	21.7	6.8	0	0	% of Total
	ANG.	-1.3	-9.2	5.5	9.0	-1.2	0	
10.8	AMORPH.	6.80	0.36	2.34	0.73	0	0	$\#/m^3 x10^6$
	ANG.	-0.14	-0.99	0.59	0.97	0.13	0	
154.	AMORPH.	0.27	0.12	6.43	16.0	0	0	$\mu gm/m^3$
	ANG.	-0.02	-0.98	4.68	61.5	65.9	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 10/25/72
FIELD PREP. Spread straw
FUEL MOISTURE ~19%
PASS ELEVATIONS 30 m
COMMENTS: Smoldering

TIME 1440
FUEL TYPE Rice
FLAME TEMPS. 555°C
INVERSION BASE(S) a) (396)
b) 701 m

TYPE Front
WIND SPEED 3-4 mps
COMBUSTION RATE 141 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1400):								
	AMORPH.	86.0	9.6	0.7	0	0	0	% of Total
	ANG.	0.2	1.4	0.2	0.7	1.0	0	
49.9	AMORPH.	43.0	4.8	0.35	0	0	0	$\#/m^3 x10^6$
	ANG.	0.10	0.70	0.10	0.35	0.50	0	
281.	AMORPH.	1.72	1.65	0.96	0	0	0	$\mu gm/m^3$
	ANG.	0.01	0.69	0.79	22.	253.	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	72.1	17.4	1.2	0	0	0	% of Total
	ANG.	0.8	1.6	2.4	4.0	0.4	0	
93.21	AMORPH.	67.3	16.2	1.12	0	0	0	$\#/m^3 x10^6$
	ANG.	0.75	1.49	2.24	3.74	0.37	0	
455.	AMORF.	2.69	5.46	3.07	0	0	0	$\mu gm/m^3$
	ANG.	0.08	1.47	17.8	237.	187.	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	56.1	26.4	1.78	0	0	0	% of Total
	ANG.	1.49	1.83	4.93	7.80	-0.3	0	
43.31	AMORPH.	24.3	11.4	0.77	0	0	0	$\#/m^3 x10^6$
	ANG.	0.65	0.79	2.14	3.39	-0.13	0	
174.	AMORPH.	0.97	3.91	2.11	0	0	0	$\mu gm/m^3$
	ANG.	0.07	0.78	16.	215	-66.	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 10/25/73
FIELD PREP. Spread
FUEL MOISTURE 19%
PASS ELEVATIONS 395 m
COMMENTS: Active plume

TIME 1420
FUEL TYPE Rice
FLAME TEMPS. 538°C
INVERSION BASE(S) 395 m; 700 m

TYPE Front
WIND SPEED 2.5 - 4 mps
COMBUSTION RATE 82.5 kg min^{-1}

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1400):								
--	AMORPH.	86.0	9.6	0.7	0	0	0	% of Total
	ANG.	0.2	1.4	0.2	0.7	1.0	0	
40.8	AMORPH.	35.1	3.92	0.29	0	0	0	$\#/m^3 x10^6$
	ANG.	0.08	0.57	0.08	0.29	0.48	0	
266.6	AMORPH.	1.40	1.34	0.80	0	0	0	$\mu gm/m^3$
	ANG.	0.01	0.56	0.63	18.4	243.5	0	
TOTAL PENETRATION PLUME LOADING:								
--	AMORPH.	93.6	4.0	0.6	0	0	0	% of Total
	ANG.	0.3	0.3	0.9	0	0.3	0	
49.8	AMORPH.	46.6	1.99	0.30	0	0	0	$\#/m^3 x10^6$
	ANG.	0.15	0.15	0.45	0	0.15	0	
83.2	AMORF.	1.86	0.68	0.83	0	0	0	$\mu gm/m^3$
	ANG.	0.02	0.14	3.57	0	76.1	0	
NET FIRE CONTRIBUTION:								
--	AMORPH.	129	-21.5	0.14	0	0	0	% of Total
	ANG.	0.8	- 4.7	4.08	-3.18	2.88	0	
9.0	AMORPH.	11.5	-1.93	0.01	0	0	0	$\#/m^3 x10^6$
	ANG.	0.07	-0.42	0.37	-0.29	-0.33	0	
(-183.)	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.	--	--	--	--	--	--	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 7/31/72
FIELD PREP. Spread
FUEL MOISTURE Na
PASS ELEVATIONS 3.95 m
COMMENTS: Spread plume

TIME 11:30
FUEL TYPE Barley
FLAME TEMPS. Na
INVERSION BASE(S) 390 m

TYPE perimeter
WIND SPEED ≈ 1.0 mps
COMBUSTION RATE Na

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (11:20):								
--	AMORPH.	55.1	32.9	10.7	1.3	0.0	0.0	% of Total
	ANG.							
3.63	AMORPH.	2.00	1.19	0.39	0.05	0.0	0.0	$\#/m^3 x10^6$
	ANG.							
4.42	AMORPH. ANG.	0.13	0.68	1.78	1.83	0.0	0.0	$\mu gm/m^3$
TOTAL PENETRATION PLUME LOADING:								
--	AMORPH.	87.1	12.4	0.3	0.0	0.0	0.0	% of Total
	ANG.	0.0	0.0	0.0	0.2	0.0	0.0	
58.43	AMORPH.	51.85	7.38	0.18	0.0	0.0	0.0	$\#/m^3 x10^6$
	ANG.	0.0	0.0	0.0	0.12	0.0	0.0	
12.2	AMORF. ANG.	3.44	3.65	0.82	4.33	0.0	0.0	$\mu gm/m^3$
NET FIRE CONTRIBUTION:								
--	AMORPH. ANG.	89.2	11.1	0.04	0.01	0.0	0.0	% of Total
54.80	AMORPH.	49.8	5.19	- .21	0.07	0.0	0.0	$\#/m^3 x10^6$
	ANG.							
7.82	AMORPH. ANG.	3.31	2.97	-0.96	2.50	0.0	0.0	$\mu gm/m^3$

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 7/31/72
FIELD PREP. Spread
FUEL MOISTURE Na
PASS ELEVATIONS 305
COMMENTS: Active plume

TIME 1100
FUEL TYPE Barley
FLAME TEMPS. Na
INVERSION BASE(S) 365 m

TYPE perimeter
WIND SPEED 1 mps
COMBUSTION RATE Na

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1045):								
--	AMORPH.	66.4	19.4	2.4	1.2	0.0	0.0	% of Total
	ANG.	0.0	3.5	2.9	2.9	1.2	0.0	
8.67	AMORPH.	5.76	1.68	0.21	0.10	0.0	0.0	$\#/m^3 x10^6$
	ANG.	0.0	0.30	0.25	0.25	0.1	0.0	
72.5	AMORPH.	0.23	0.58	0.68	2.20	0.0	0.0	$\mu gm/m^3$
	ANG.	0.0	0.30	1.98	15.86	50.72	0.0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	87.9	11.4	0.3	0.0	0.0	0.0	% of Total
--	ANG.	0.0	0.0	0.2	0.3	0.0	0.0	
78.6	AMORPH.	69.1	8.96	0.24	0.0	0.0	0.0	$\#/m^3 x10^6$
	ANG.	0.0	0.0	0.16	0.24	0.0	0.0	
	AMORF.	2.76	3.08	0.76	0.0	0.0	0.0	$\mu gm/m^3$
23.11	ANG.	0.0	0.0	1.28	15.23	0.0	0.0	
NET FIRE CONTRIBUTION:								
--	AMORPH.	90.4	10.4	0.04	-0.14	0.0	0.0	% of Total
	ANG.	0.0	-0.43	0.13	-0.01	-0.14	0.0	
69.9	AMORPH.	63.3	7.28	0.03	-0.10	0.0	0.0	$\#/m^3 x10^6$
	ANG.	0.0	-0.30	-0.09	-0.01	-0.1	0.0	
(-49.4)	AMORPH.	--	--	--	--	--	--	$\mu gm/m^3$
	ANG.	--	--	--	--	--	--	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 11/1/72 | TIME 1445 | TYPE Pile burn
FIELD PREP. Stacked straw | FUEL TYPE Rice | WIND SPEED 1 - 1.5 mps
FUEL MOISTURE 11.2% | FLAME TEMPS. 120 - 232°C | COMBUSTION RATE ~17 kg min^{-1}
PASS ELEVATIONS ~90 m | INVERSION BASE(S) 550 m
COMMENTS: Late smoldering stage

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1435):								
	AMORPH.	83.4	12.7	1.5	0	0	0	% of Total
	ANG.	0	0	2.0	0.5	0	0	
5.15	AMORPH.	4.29	0.65	0.08	0	0	0	$\#/m^3 x 10^6$
	ANG.	0	0	0.10	0.03	0	0	
3.07	AMORPH.	0.17	0.22	0.21	0	0	0	$\mu gm/m^3$
	ANG.	0	0	0.82	1.65	0	0	
TOTAL PENETRATION PLUME LOADING:								
	AMORPH.	59.9	23.1	3.4	0	0.7	0	% of Total
	ANG.	0	1.4	7.5	1.4	2.7	0	
20.7	AMORPH.	12.4	4.77	0.70	0	0.14	0	$\#/m^3 x 10^6$
	ANG.	0	0.29	1.55	0.29	0.56	0	
343.	AMORF.	0.49	1.63	1.93	0	25.3	0	$\mu gm/m^3$
	ANG.	0	0.29	12.4	18.3	282.	0	
NET FIRE CONTRIBUTION:								
	AMORPH.	52.1	26.6	4.0	0	0.9	0	% of Total
	ANG.	0	1.9	9.3	1.7	3.6	0	
15.6	AMORPH.	8.11	4.1	0.62	0	0.14	0	$\#/m^3 x 10^6$
	ANG.	0	0.29	1.45	0.26	0.56	0	
339.	AMORPH.	0.32	1.41	1.72	0	25.3	0	$\mu gm/m^3$
	ANG.	0	0.29	11.6	16.7	282.	0	

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 6/28/72
FIELD PREP. Spread
FUEL MOISTURE 4%
PASS ELEVATIONS 150-365 m
COMMENTS:

TIME 1430
FUEL TYPE Early
FLAME TEMPS. Na
INVERSION BASE(S) 395 m

TYPE Front
WIND SPEED 3 mps
COMBUSTION RATE Na

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1530):								
	AMORPH. / ANG.	94	3.8	1.6	0.5	0.2	0.0	% of Total
3.0	AMORPH. / ANG.	2.82	0.11	0.048	0.015	0.006	0.0	$\#/m^3 x10^6$
2.78	AMORPH. / ANG.	0.19	0.06	0.22	0.55	1.76	0.00	$\mu gm/m^3$
TOTAL PENETRATION PLUME LOADING:								
	AMORPH. / ANG.	76.7	19.6	2.2	1.1	0.3	0.04	% of Total
7.8	AMORPH. / ANG.	5.98	1.50	0.17	0.086	0.023	0.003	$\#/m^3 x10^6$
19.1	AMORF. / ANG.	0.40	0.97	0.78	3.15	8.75	7.03	$\mu gm/m^3$
NET FIRE CONTRIBUTION:								
	AMORPH. / ANG.	65.5	29.5	2.5	1.5	0.4	0.6	% of Total
4.8	AMORPH. / ANG.	3.16	1.59	0.122	0.071	0.017	0.003	$\#/m^3 x10^6$
16.3	AMORPH. / ANG.	0.21	0.91	0.56	2.60	4.87	7.03	$\mu gm/m^3$

FIRE PLUME PENETRATION DATA - PARTICULATES

DATE 6/28/72
FIELD PREP. Spread
FUEL MOISTURE 4%
PASS ELEVATIONS 150 - 395 m
COMMENTS:

TIME 1500
FUEL TYPE Barley
FLAME TEMPS. Na
INVERSION BASE(S) 395 m

TYPE Backfire
WIND SPEED 2.5 mps
COMBUSTION RATE Na

TOTAL LOADING	PHYSICAL APPEARENCE	SIZE DISTRIBUTION PARTICLE DIAMETERS BY RANGES 0.4-0.7	0.7-1.3	1.3-2.7	2.7-5.3	5.3-10.6	>10.6	UNITS microns
BACKGROUND DATA (1530):								
	AMORPH. / ANG.	94.0	3.8	1.6	0.5	0.2	0.0	% of Total
2.00	AMORPH. / ANG.	1.88	0.076	0.032	0.010	.004	0.00	$\#/m^3 x10^6$
1.11	AMORPH. / ANG.	0.07	0.03	0.09	0.22	0.70	0.0	$\mu gm/m^3$
TOTAL PENETRATION PLUME LOADING:								
	AMORPH. / ANG.	63.5	29.5	4.8	1.8	0.4	0.00	% of Total
3.54	AMORPH. / ANG.	2.25	1.04	0.17	0.064	.014	0.00	$\#/m^3 x10^6$
4.78	AMORF. / ANG.	0.08	0.36	0.47	1.41	2.46	0.00	$\mu gm/m^3$
NET FIRE CONTRIBUTION:								
	AMORPH. / ANG.	24.1	62.6	9.1	3.5	0.7	0.0	% of Total
1.54	AMORPH. / ANG.	0.37	0.96	.13	.054	.010	0.0	$\#/m^3 x10^6$
3.67	AMORPH. / ANG.	0.01	0.33	0.38	1.19	1.76	0.0	$\mu gm/m^3$